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CONTINUING EDUCATION

ELECTRONIC TEST EQUIPMENT:

OSCILLOSCOPES

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You may find a 100 Ω (brown-black-brown) resistor packed with the other components supplied with this module. If you do, you may discard this resistor; it will not be needed.

Thank you,

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TEST EQUIPMENT

OSCILLOSCOPES

MODEL EE-3105-2
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INTRODUCTION

This Individual Learning Program contains unit 3 of a comprehensive course on electronic test equipment. The complete course contains the following six units, which are arranged into four modules:

Program Number	Units	Title
EE-3105-1	1 & 2	Analog and Digital Meters
EE-3105-2	3	Oscilloscopes
EE-3105-3	4 & 5	Frequency Generation and Measurement
EE-3105-4	6	Special Measuring Instruments

You can take any one of these modules alone, or with any of the other modules. One module is not a prerequisite for another.

A Unit Examination is included for each unit of the course. This test is for your benefit and will not be graded by Heath Company.

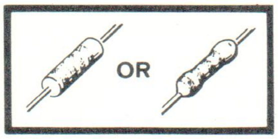
A **Certificate of Achievement** and an appropriate number of "Continuing Education Units" will be awarded to those who complete all four modules and take the Final Examination. You can obtain the Final Examination at no additional charge by sending the signed "Completion Verification Statements" from each of the four modules to Heath. An addressed envleope is included for this purpose in the last of the four modules, "EE-3105-4, Special Test Equipment." If you purchase the complete course, "EE-3105, Electronic Test Equipment", the Final Examination will be included with the course materials.

PARTS LIST

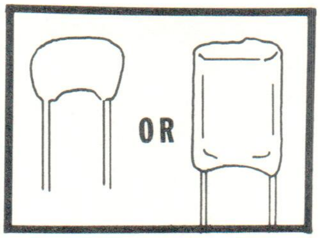
This Parts List contains all of the parts you will need for the Experiments you will perform in this module. The key numbers correspond to the numbers in the illustrations. Some parts are packaged in envelopes. Except for this initial parts check, keep these parts in their envelopes until they are called for in an Experiment.

KEY No.	PART No.	QTY.	DESCRIPTION
RESISTORS			
A1	1-102-12	1	1 kΩ, 1/4 watt, 5%
A1	1-822-12	1	8.2 kΩ, 1/4 watt, 5%
CAPACITORS			
A2	20-148	1	100 pF mica
A3	21-95	1	0.1 μF disc ceramic
INTEGRATED CIRCUITS			
A4	443-7	1	SN7490

A 1

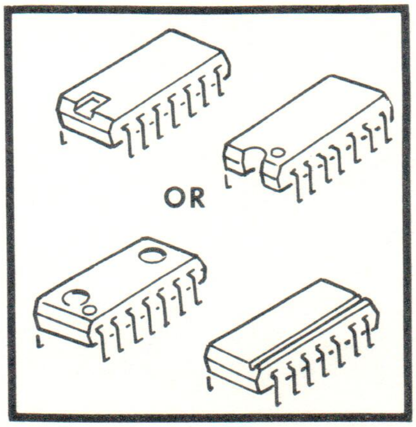


A2



A3

A4



Unit 3

OSCILLOSCOPES

EE-3105

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INTRODUCTION

Oscilloscopes are very useful test instruments for testing and designing in electronics. There are an almost infinite number of wave shapes that can exist. There are sine waves, square waves, triangular waves and combinations of these and other waves. In a defective circuit, the wave shapes may contain undesirable voltages. These voltages can be detected by a meter. If the shape of the voltage waveform is known, the average, peak, rms, or peak-to-peak value of voltage can be determined. However, there is no way to determine with a meter whether the voltage measured is caused by the desired waveform or by noise.

Also, in many instances, it is not the amplitude but the shape and timing which are most important. Only with the oscilloscope can we look at the shape and spacing of electrical signals. Thus, with an oscilloscope, we can see what is happening inside our television or computer.

In this section, we will discuss the components and circuits which make up the oscilloscope. We will also discuss the function and operation of the various controls and how to interpret various scope presentations.

UNIT OBJECTIVES

When you have completed this unit, you should be able to:

1. Identify the various parts of a cathode ray tube from a drawing of the CRT.
2. Select the purpose of the various parts of the CRT.
3. Select the description of how the electron beam is deflected within the CRT.
4. Select the definition of deflection sensitivity.
5. Select the definition of bandwidth.
6. Identify the difference between horizontal and vertical deflection circuits.
7. Identify the purpose of blanking and unblanking.
8. Identify the difference between triggered and free-running sweeps.
9. Identify the advantage of a triggered sweep.
10. Select the definition of rise time.
11. Select a statement that describes how bandwidth and rise time are related.

12. Identify the requirements of an oscilloscope power supply.
13. Identify the purpose of a sweep magnifier.
14. Select a statement that describes the operation of a delayed sweep.
15. Identify three ways dual trace presentation can be obtained.
16. Select a statement that explains the difference between chop and alternate methods of dual trace development.
17. Select a statement that explains the operation of a storage scope.
18. Select a statement that explains the use of a sampling scope.
19. Identify the various oscilloscope controls and explain the purpose of each.
20. Select a statement that describes how AC and DC voltages are measured with an oscilloscope.
21. Select a statement that describes how time and frequency are measured with a calibrated sweep.
22. Select a statement that describes pulse measurements and how they are made.
23. Select a statement that describes the use of Lissajous figures for making phase and frequency measurements.

UNIT ACTIVITY GUIDE

	Completion Time
☐ Read the Section on the Cathode Ray Tube.	________
☐ Complete Programmed Review Frames 1 - 20.	________
☐ Read the Section on Oscilloscope Circuits.	________
☐ Complete Programmed Review Frames 21 - 43.	________
☐ Read the Section on Special Features.	________
☐ Complete Programmed Review Frames 44 - 61.	________
☐ Read the Section on Controls.	________
☐ Complete Programmed Review Frames 62 - 77.	________

☐ Complete Experiment 5. ____________

☐ Read the Section on Oscilloscope Measurements. ____________

☐ Complete Programmed Review Frames 78 - 92. ____________

☐ Complete Experiment 6. ____________

☐ Complete Experiment 7. ____________

☐ Complete Unit Examination ____________

☐ Check Examination Answers. ____________

CATHODE RAY TUBE

The heart of the oscilloscope is the cathode ray tube (CRT) just as the picture tube is the heart of your television set. The CRT is similar in many respects to the picture tube in a black and white television and could, in fact, be used to display a TV picture. There are three basic parts to the CRT: the phosphor screen, the deflection plates, and the electron gun as shown in Figure 1. The phosphor screen can be thought of as a piece of electronic graph paper upon which such details as amplitude, phase, frequency, distortion, pulse duration, and shape may be plotted. The screen is composed of a phosphor coating on the inside of the face of the CRT.

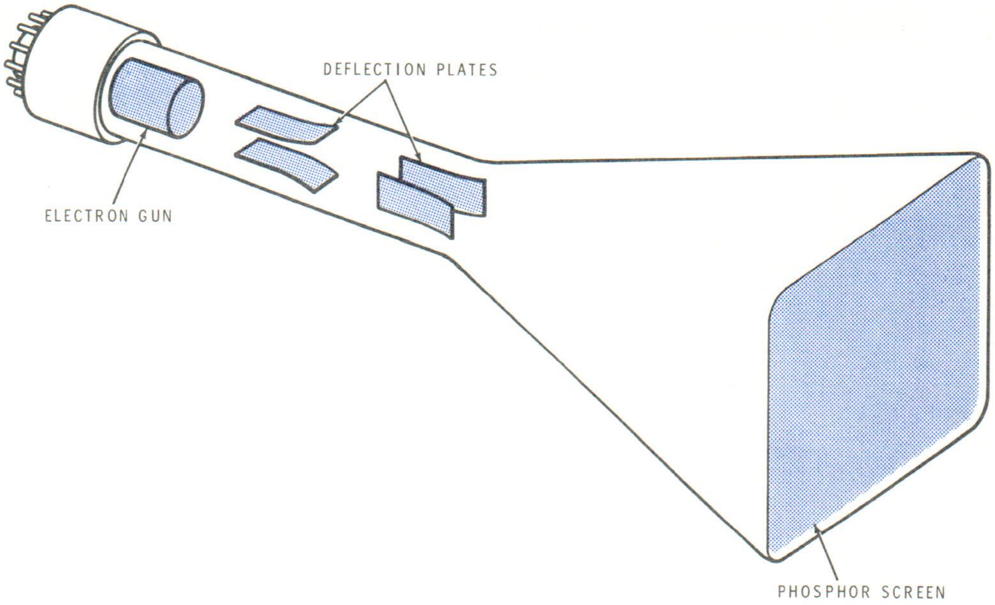


Figure 1

Phosphors are materials which give off light when struck by electrons. There is light emission during electron bombardment, which is called **fluorescence**. There is also a continued emission after bombardment stops, which is known as **phosphorescence**. The length of time that a phosphor continues to glow after bombardment stops is the **persistence** of the phosphor.

There are approximately forty different phosphors used for coatings on CRT's. Only a few of these are suitable for use with oscilloscopes. Others may be used for radar, television, computers, and various other displays.

Phosphors are available in white, yellow, orange, red green, blue, and combinations of these. Persistence varies from less than a microsecond to more than a minute.

In selecting a phosphor, the designer must consider the characteristics of the signal being displayed and the response of the human eye. The signal that is displayed by an oscilloscope may be one that is changing very slowly which suggests a long persistence, or it may be changing rapidly and need a shorter persistence. In practice, a compromise is made, with persistence times being between fifty microseconds and fifty milliseconds. Of course, designers may deviate from these limits depending on the application.

The human eye responds best to some form of green light. Phosphors in this color group that fulfill the persistence requirement are green and yellowish green. These are the colors most often seen in oscilloscopes.

The Electron Gun

The electron gun provides a very fine beam of high velocity electrons that bombard the screen. The electron gun is shown in Figure 2. The electron gun is composed of five sections. The cathode (k) and the four grids are shown as they are mounted in the tube. In this particular CRT, the elements are held in place by insulated supporting rods. Although they are not considered a part of the electron gun, the vertical and horizontal deflection plates are shown here to illustrate their physical placement in the tube.

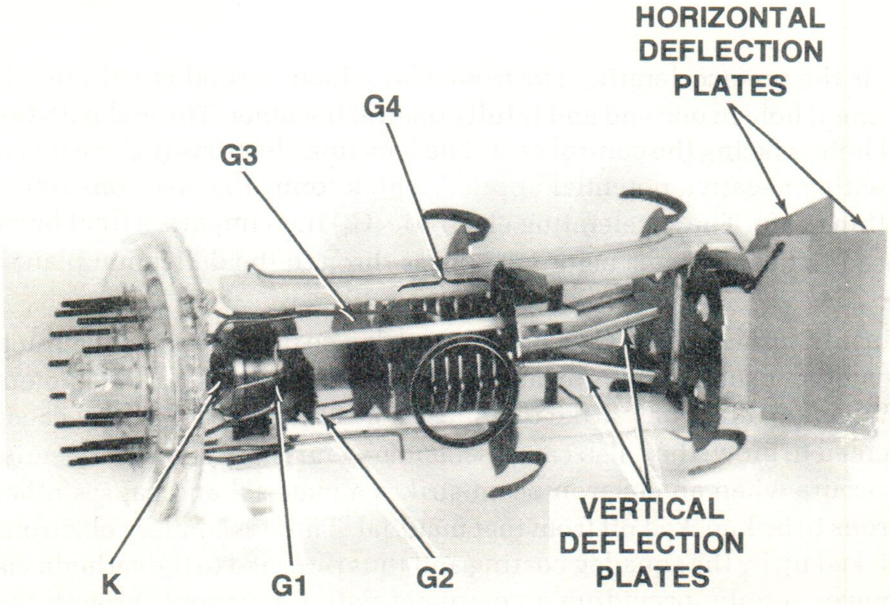


Figure 2

An exploded view of the electron gun is shown in Figure 3. The cathode is a cylindrical metal disc coated with barium sulphate and heated by the heater. When heated inside a vacuum, barium sulphate releases some of its electrons into the surrounding space. These electrons form a **cloud** around the cathode. This cloud of electrons is known as a **space charge** and becomes the source of electrons for the CRT. The control grid (G_1) often called a "Wehnelt cylinder" partially encloses the cathode. Electrons are allowed to escape through a small hole opposite the cathode.

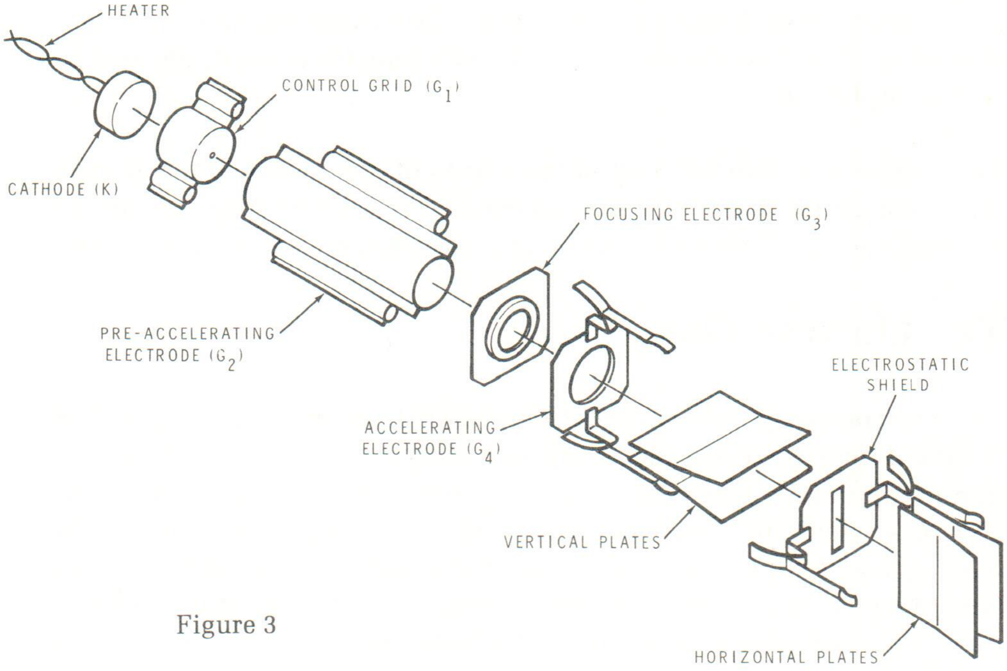

HEATER
CONTROL GRID (G_1)
CATHODE (K)
FOCUSING ELECTRODE (G_3)
PRE-ACCELERATING ELECTRODE (G_2)
ELECTROSTATIC SHIELD
ACCELERATING ELECTRODE (G_4)
VERTICAL PLATES
HORIZONTAL PLATES

Figure 3

Next, is the pre-accelerating electrode (G_2) which is another cylinder. It has a small hole in one end and is fully open at the other. The end with the small hole is facing the control grid. The focusing electrode (G_3) is a metal ring with a negative potential applied which forms the electrons into a very thin beam. The accelerating electrode (G_4) then imparts a final burst of speed to the electrons before they pass through the deflection plates.

The inside surface of the CRT has an aquadag coating (this is a conducting material, usually graphite) and is connected to a high positive potential. When the electrons strike the phosphor screen, they not only cause the screen to glow, they also cause secondary emission. Secondary emission occurs when an electron beam strikes a material and causes other electrons to be knocked off from that material. These secondary electrons are picked up by the aquadag coating and thus returned to the cathode via the power supply, providing a completer path for current through the CRT.

The effect of the various grids on the electron beam can be seen in Figure 4. The heated cathode emits a cloud of electrons. The negative voltage on G_1 forms the electrons into a slightly divergent beam. These electrons are attracted by G_2, which is positive. Electrons which pass through the aperture of G_2 are accelerated toward the screen in a divergent beam. The negative voltage on G_3 causes the electrons to converge such that they arrive at the screen as a very fine point. G_4 aids in the convergence of the beam and gives a final acceleration to the electrons.

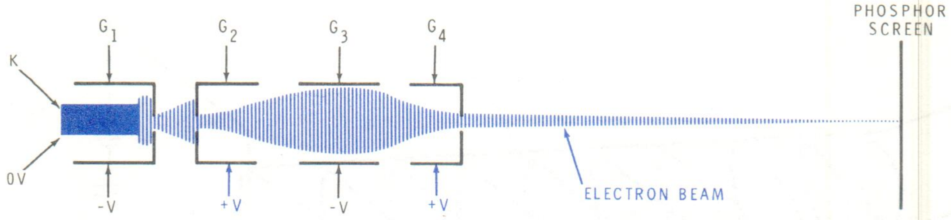


Figure 4

The acceleration provided by the electron gun is adequate for a low frequency scope with a maximum bandwidth of about 5 MHz. At higher frequencies, the beam moves across the phosphor screen at such a speed that the trace brightness decreases. Therefore, the energy of the electrons striking the screen must be increased.

More energy could be given to the electrons by increasing the potentials on the electron gun. However, this will require increased voltages or increased area for the deflection plates. Either of these can cause a decrease in frequency response of the scope. It is better to accelerate the electrons after they pass the deflection plates. This is called "post deflection acceleration."

The easiest method of providing post deflection acceleration is by a resistive helix wound inside the tube as shown in Figure 5. With a high positive voltage applied to the screen end of the helix, electrons will be progressively accelerated until they strike the screen. The main drawback to this method of acceleration is increased CRT length.

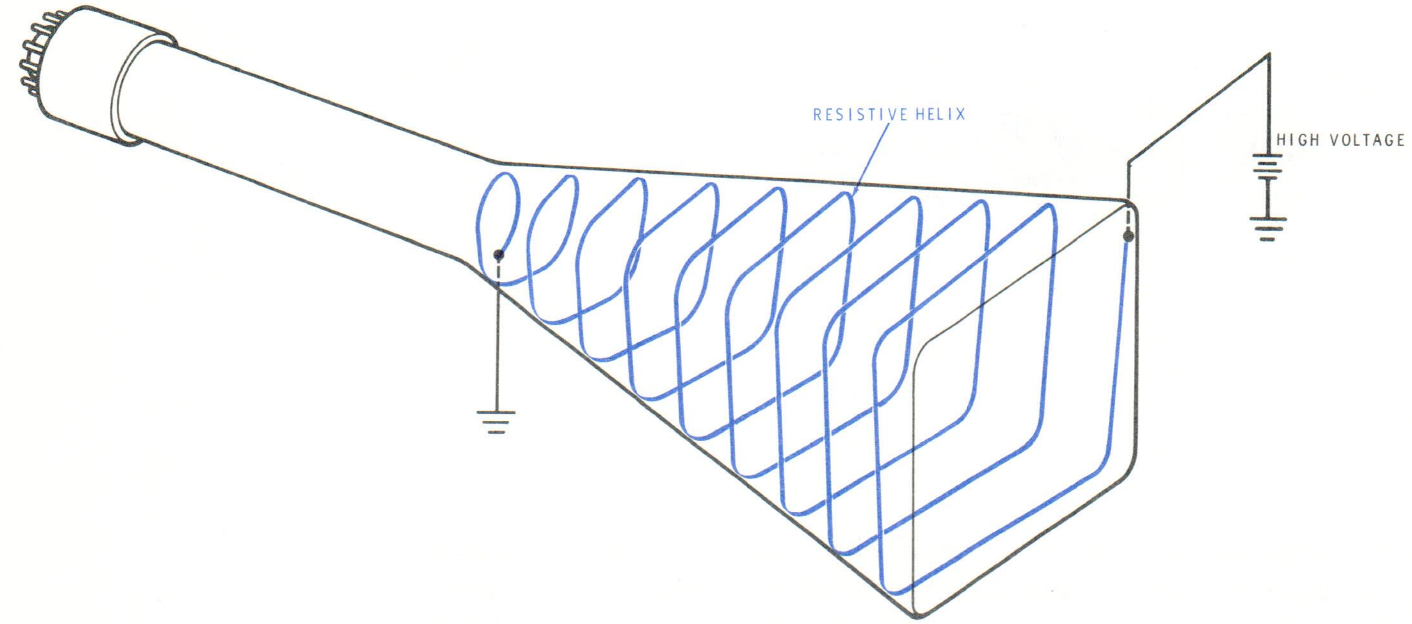


Figure 5

A method of providing considerable electron acceleration in a tube which is much shorter than one using the helix is the high-contoured expansion mesh designed by Hewlett-Packard. The mesh is mounted on the screen side of the deflection plates and connected to electron gun potential as shown in Figure 6. The inside surface of the CRT is coated with a conductive material.

When a high positive potential is applied to the conductive material, a strong electrostatic field is established between the mesh and the wall of the CRT. This field is depicted in Figure 6. Notice that the field is spherical in shape so that, while the electrons are accelerated, their direction is not changed. This type of post deflection acceleration requires a tube less than one half as long as is required for the same size display using a helix.

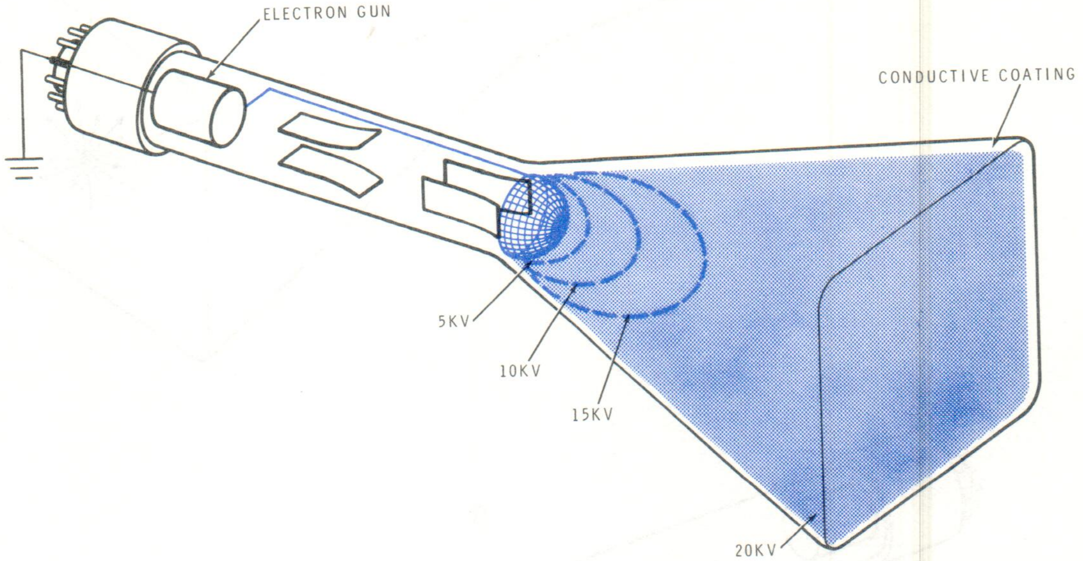


Figure 6

Brightness can also be improved by insuring that all of the light emitted by the phosphor is seen by the viewer. This may be accomplished by **aluminizing** the screen.

Figure 7A shows what happens with a screen that is not aluminized. The electron beam strikes the phosphor, causing it to emit light. Here, the light is emitted in all directions with only a small portion going toward the viewer. However, when the tube has been aluminized, by vapor depositing a very thin layer of aluminum over the rear of the screen, most of the light is reflected toward the viewer as shown in Figure 7B. This gives a significant increase in brightness.

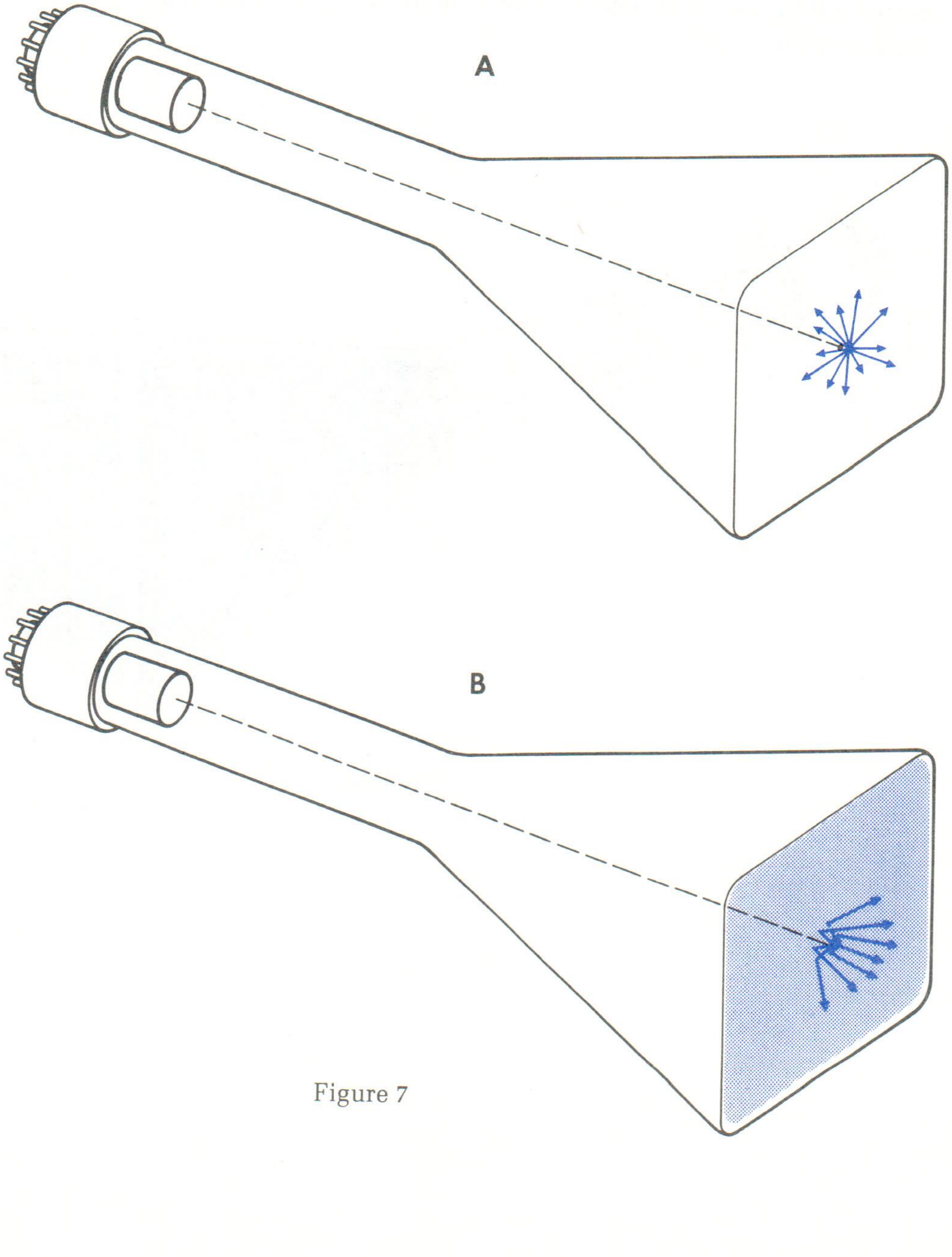


Figure 7

Beam Deflection

The beam from the electron gun travels in a straight line and forms a small dot on the screen. With no external influence, the beam should strike the center of the screen. For the scope to be useful, the beam must be moved or deflected in both horizontal and vertical directions.

There are two methods of beam deflection in a CRT: electromagnetic and electrostatic.

ELECTROMAGNETIC DEFLECTION

Electromagnetic deflection is the type used with TV picture tubes. The beam is deflected by magnetic fields produced by coils arranged around the outside of the tube. The size of the deflection coils increases as frequency increases, and becomes prohibitive at higher frequencies. While magnetic deflection gives better resolution, it is seldom used in oscilloscopes due to an upper frequency limit of approximately 5 MHz.

ELECTROSTATIC DEFLECTION

Electrostatic deflection, which is used in most oscilloscopes, works on the principle that unlike charges attract and like charges repel. To accomplish this, a set of deflection plates is installed inside the tube just after the electron gun. The vertical plates usually come first, followed by the horizontal plates. The relationship of the vertical and horizontal deflection plates is shown in Figure 8. With no difference in potential across the plates, the beam will strike the center of the screen as shown.

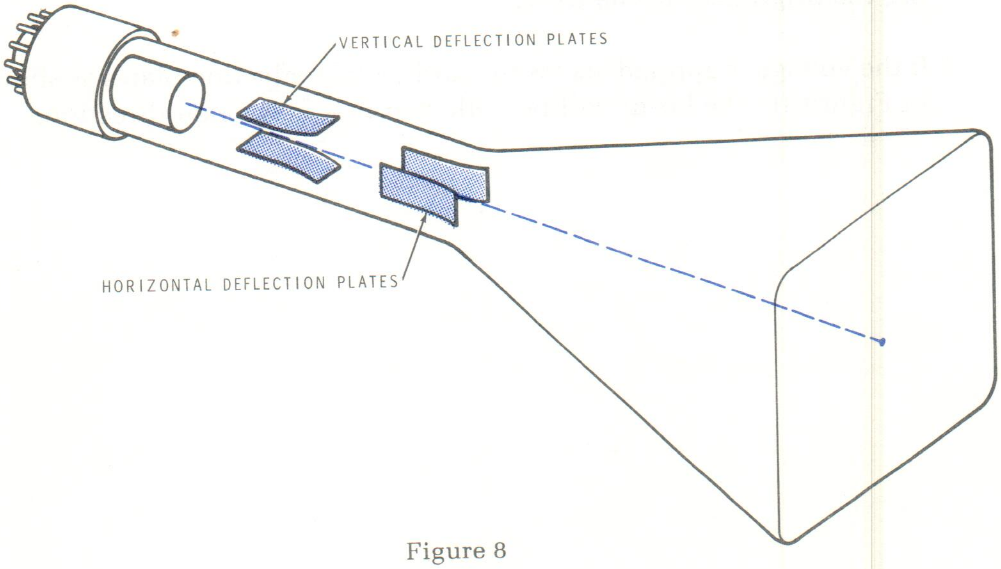


Figure 8

When a potential is connected across the vertical plates, as shown in Figure 9, the electron beam will be deflected away from the negative plate toward the positive plate. The amount of deflection is proportional to the voltage applied to the plates.

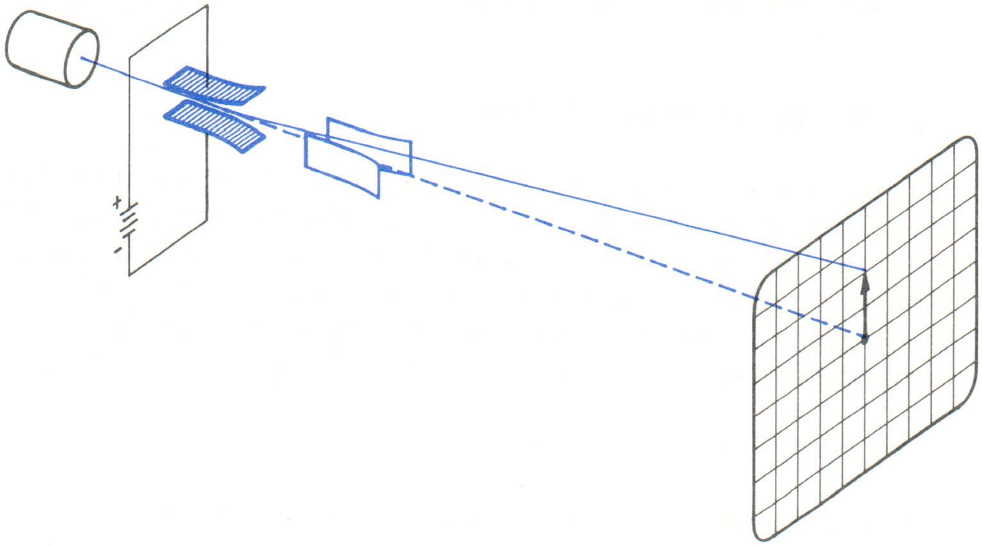


Figure 9

Notice that one plate is positive while the other is negative, giving an overall potential of 0 V for the plates. This is necessary to avoid changing the acceleration of the electrons with the deflection voltage; thus changing the brightness of the trace.

If the voltage is applied across the horizontal deflection plates as shown in Figure 10, the beam will be deflected in a horizontal direction.

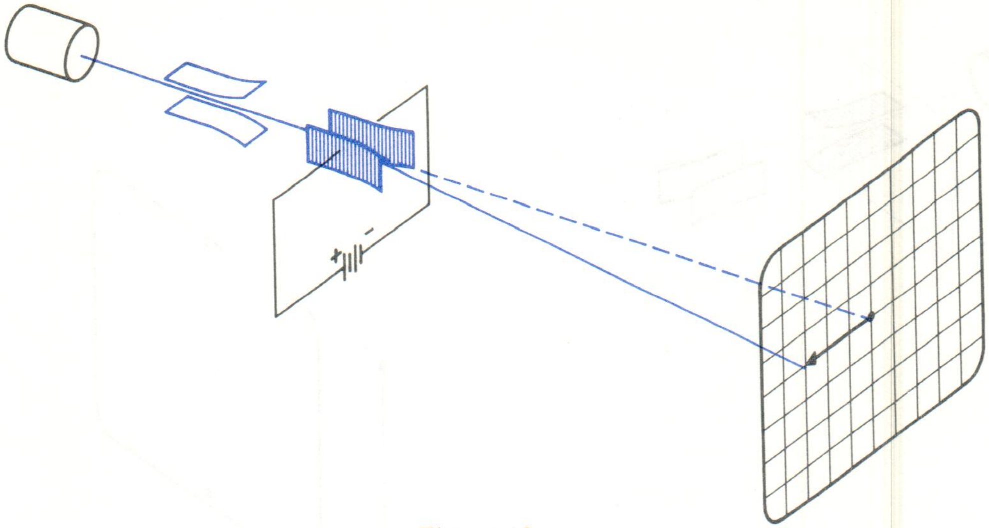


Figure 10

DEFLECTION SENSITIVITY

If we look at the placement of the deflection plates within the CRT, we find that the vertical deflection plates are nearer the electron gun and farther from the screen than the horizontal plates. Thus, a smaller angular deflection is required by the vertical plates for a given distance of spot travel on the screen than is required by the horizontal plates.

A "typical" CRT requires from eight to twelve volts of potential difference between the vertical deflection plates for a deflection of 1 cm on the screen. The voltage required for a 1 cm deflection is known as the deflection sensitivity; therefore, we could say that the vertical sensitivity of a typical CRT is 10 V/cm. This does not mean that the vertical sensitivity of the oscilloscope is 10 V/cm. Amplifiers are used to increase the sensitivity far beyond that of the CRT.

We have already seen that the horizontal sensitivity is less than the vertical sensitivity. Horizontal deflection usually requires between 15 and 20 V/cm.

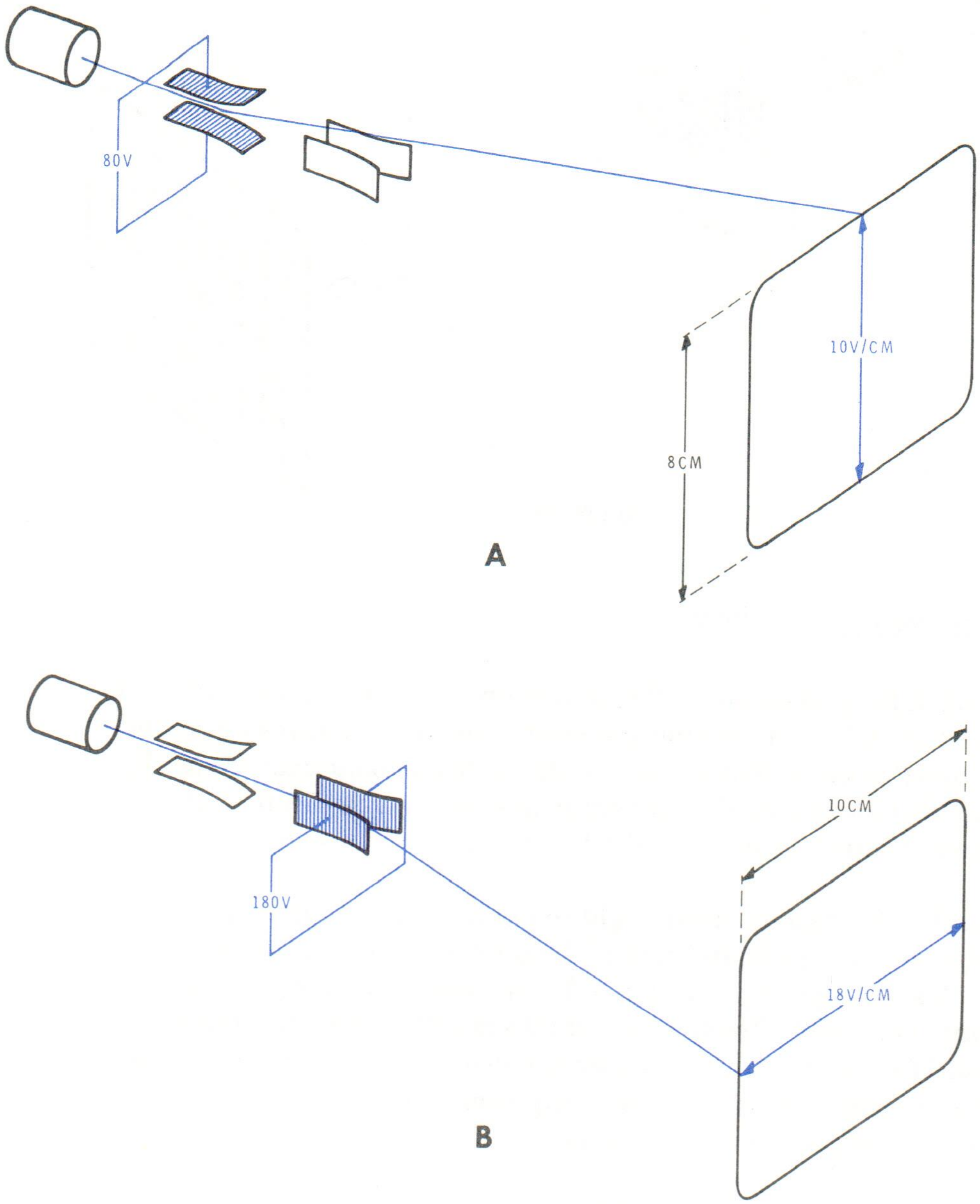


Figure 11

A common display size is 8 × 10 cm. Thus, if the vertical deflection sensitivity is 10 V/cm, 80 V must be applied to the vertical deflection plates for full deflection as illustrated in Figure 11A. As shown here, the top plate will be positive 40 V and the bottom plate negative 40 V, for a difference of 80 V. It is common for both plates to be at some positive potential. The actual potential is unimportant as long as the difference is 80 V.

Using the same size display with a horizontal deflection sensitivity of 18 V/cm, a potential of 180 volts must be applied to the horizontal plates as shown in Figure 11B. Once more, the actual potential on the plates is irrelevant as far as deflection is concerned. It is the potential difference between the plates that counts.

The actual potential on the plates does have some effect on focus and brightness. Therefore, when the deflection potential goes positive on one plate, it must go negative by a like amount on the opposite plate so that the overall potential remains constant.

We have discussed the construction and use of the CRT, and used illustrations which show the physical and electrical relationship of the tube components. As we develop the circuits which work with the CRT to make an oscilloscope, we will be primarily concerned with the electrical characteristics only. Schematically, the CRT is represented as shown in Figure 12. This representation will be used as we continue.

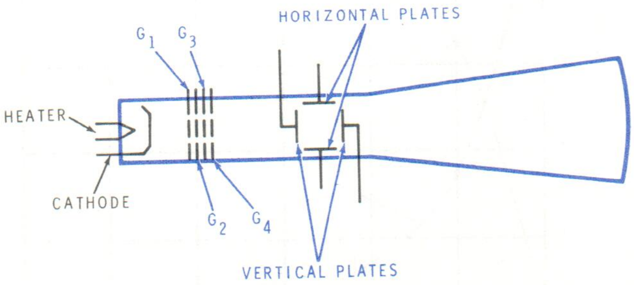


Figure 12

DEFLECTION CIRCUITS

Before we start our discussion of deflection circuits, we will review some necessary basics.

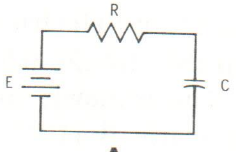
If a capacitor is connected across a power source as shown in Figure 13A, the capacitor will charge to the value of E. The time required for the capacitor to charge to a given value is a function of the value of R and C. This time may be calculated by the formula:

$$T = RC$$

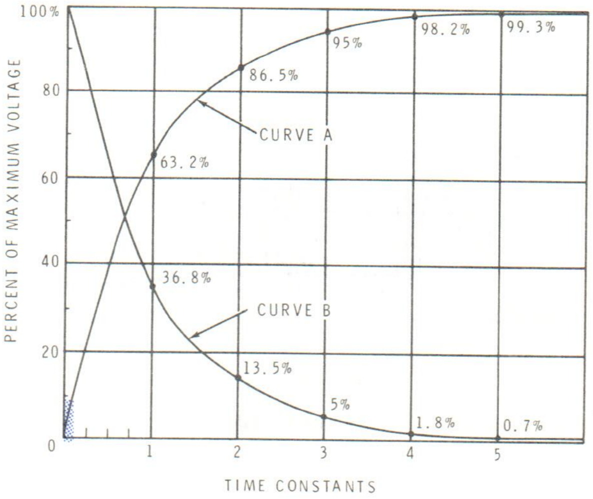
Where T = time in seconds

R = resistance in Ohms

C = capacitance in farads.



A



B

Figure 13

In one time constant (T), the capacitor will charge to a 63.2% of E as shown in Figure 13B curve A. Thus, for a capacitor to charge quickly, the value of R and C must be made as low as possible. Another way to reduce the time required to reach a given voltage is to make the supply voltage much greater than the desired voltage on C. If E is 10 times the value that C is required to charge to, then C will reach the required voltage in only 0.1 time constants. Also, the change will be in the linear portion of the charge curve as shown in Figure 13B.

If we relate the circuit shown in Figure 13A to an oscilloscope, C becomes the capacitance of the plates and R becomes the effective resistance of the vertical or horizontal amplifier. In a general-purpose oscilloscope, the deflection plates have a capacitance of about 5 pF. As you will see in the section on rise time, in a 15 MHz scope, the vertical amplifier must be capable of charging that capacitance to the desired voltage within about 25 nS.

The requirements of the horizontal amplifier are similar to those of the vertical amplifier except that a **higher** voltage is required on the horizontal plates.

It is also possible to view the deflection circuits in the frequency domain instead of the time domain. The amplifier can be treated as an AC generator with the output applied to an RC circuit as shown in Figure 14A.

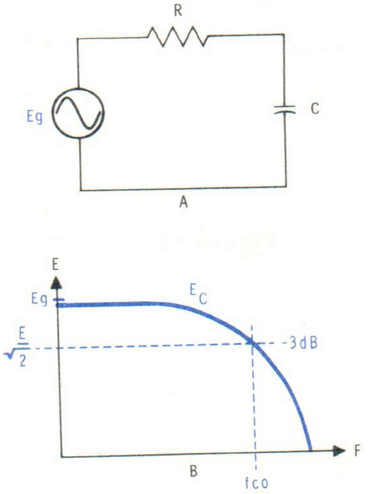


Figure 14

At the lower frequencies, almost the entire voltage is developed across C. However, as frequency increases, X_c decreases, causing the resistance to drop a higher portion of the voltage. When the voltage across the capacitor decreases to the half power point (−3 dB), the cut-off frequency of the scope (f_{co}) has been reached. This is the upper frequency limit of the scope. The voltage applied to the deflection plates at this frequency is .707 times the original voltage as shown in Figure 14B.

Thus, we can see that the design of the vertical and horizontal amplifiers affect both the bandwidth of the scope and the fidelity with which it displays certain waveforms.

Horizontal Sweep

The most basic display which can be obtained on an oscilloscope is a straight horizontal line across the screen. This is called a sweep or a trace. To see how this sweep is developed, look at Figure 15.

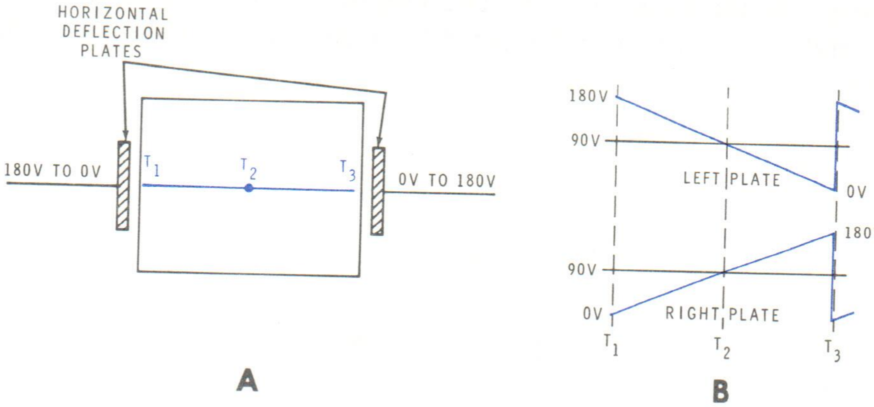


Figure 15

Each of the horizontal deflection plates has a voltage applied which can vary from 0 V to 180 V. The action begins with the left plate at 180 V and the right plate at 0 V. The electron beam will be deflected to the more positive potential. Since deflection potential is maximum, the deflection will be maximum, placing the beam at the extreme left of the screen as shown at T_1 in Figure 15.

As time passes, the sweep circuits cause the voltage on the left plate to decrease and the voltage on the right plate to increase. This causes the beam to be deflected to the right. At time T_2, both plates are at 90 V and there is no difference of potential between them; therefore, there is no deflection voltage and the beam is at the center of the screen as shown at T_2.

As time continues, the voltage on the left plate continues to decrease while the voltage on the right plate increases. At T_3, the left plate will be at 0 V and the right plate will be at 180 V, placing the beam at the right edge of the screen.

If, at the end of the sweep, we cause the deflection voltage to snap back to its original potential, we can start the sweep over again. In practice, the sweep is repeated continuously, causing the sweep to appear as a constant line across the CRT.

Remember that the beam is always producing a small dot on the screen. However, if the beam is swept across the screen at a high enough speed, the persistence of the phosphor coating and the characteristics of the human eye cause it to appear as a solid line or trace on the scope. As sweep speed becomes slower and slower, the trace will first begin to flicker. Then at even slower speeds, it becomes possible to discern the spot of light moving across the screen.

Do not stop the beam in its movement across the scope. This will concentrate the energy in one spot and possibly burn the phosphor. If the phosphor is burned, a dark spot will appear on the screen and remain there forever.

Vertical Deflection

The vertical deflection plates work very much like the horizontal deflection plates. Figure 16 illustrates how a vertical trace is developed.

As the action starts at T_0, both the upper deflection plate (plate A) and the lower deflection plate (plate B) have a potential of 50 V. There is no potential difference and the beam is centered on the screen. At this time, plate A starts going more positive while plate B becomes less positive. A potential difference is thus developed which causes the beam to deflect toward plate A. At time T_1, plate A will be at a maximum positive potential and plate B will be at 0 V. The beam will be deflected in the maximum upward direction and a line will be drawn from Y_0 to Y_1.

As time continues, the voltage on plate A starts in a negative direction and the voltage on plate B in a positive direction. The beam starts to move from Y_1 back toward Y_0. At T_2, both plates have returned to 50 V and the beam is back in the center of the screen. The plate potential continues to change, with plate B going positive and plate A becoming negative. This deflects the beam toward Y_2 and, at T_3, a line will have been drawn to the bottom of the screen. At T_4, the beam is back at the center.

As long as this signal is applied to the vertical deflection plates, the beam will continue to draw a vertical line on the screen.

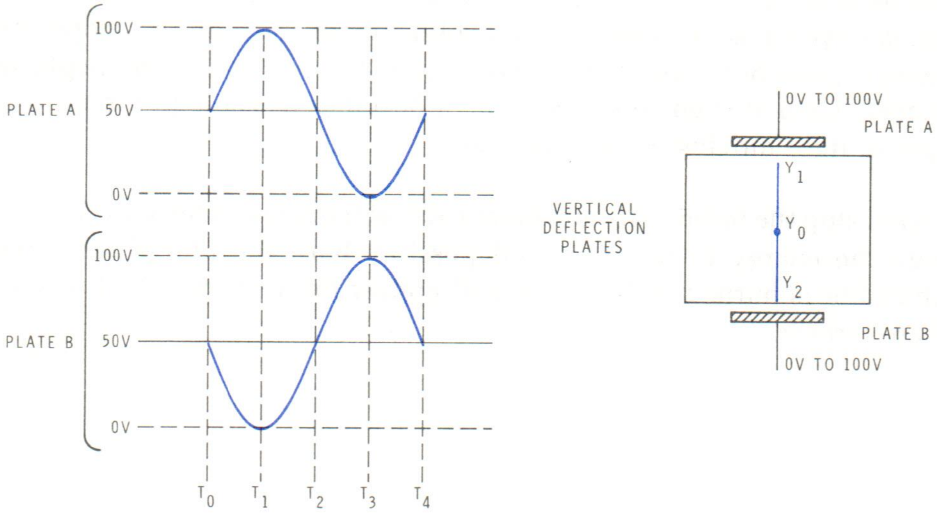


Figure 16

Developing a Presentation

We have seen how a horizontal sweep or a vertical trace can be developed on an oscilloscope. However, neither by itself does any good. For the scope to be useful, it must present some information about the incoming signal.

One of the desirable characteristics of an oscilloscope is its ability to display the frequency or period of a signal. To do this, there must be some method of comparing the incoming signal to time. Figure 17 shows how this is done.

At T_0, the horizontal deflection voltage is at its maximum negative value, which places the electron beam at the extreme left of the screen. At the same time, the sine wave which is applied to the vertical deflection plates is at 0 V.

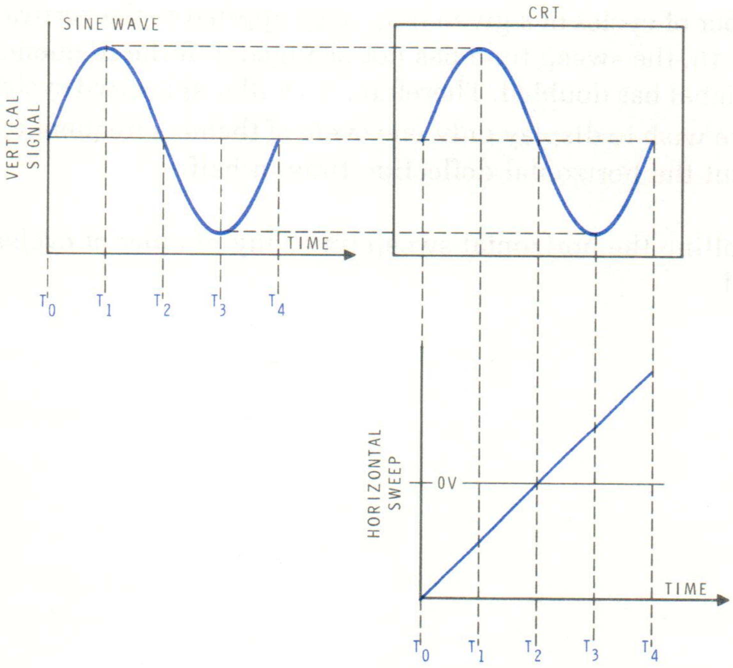


Figure 17

At T_1, the horizontal deflection voltage is at a more positive potential, which moves the beam from left to right. However, the vertical deflection voltage is now positive, which moves the beam toward the top of the screen. At T_2, the horizontal trace is passing through the center of the screen and the sine wave is at the 180° point. As the horizontal voltage continues to sweep in a positive direction moving the trace from left to right, the sine wave continues its excursion. At T_4, the horizontal voltage has reached maximum and the sine wave has completed one cycle. Thus, we can see that if the time of the horizontal sweep is exactly equal to the period of one sine wave, then we can display one sine wave on the screen.

If we know how long it takes the horizontal plate to deflect the beam from left to right, we can calculate the frequency of the waveform on the vertical plates by the formula

$$f = \frac{1}{T}$$

By controlling the time required for horizontal deflection, we can display any number of cycles of a given frequency applied to the vertical plates. In Figure 18, the sweep time has not changed, but the frequency of the vertical signal has doubled. Therefore, we will display two cycles on the CRT. If we wish to display only one cycle of the new frequency, we will have to cut the horizontal deflection time in half.

By controlling the horizontal sweep time, any number of cycles can be displayed.

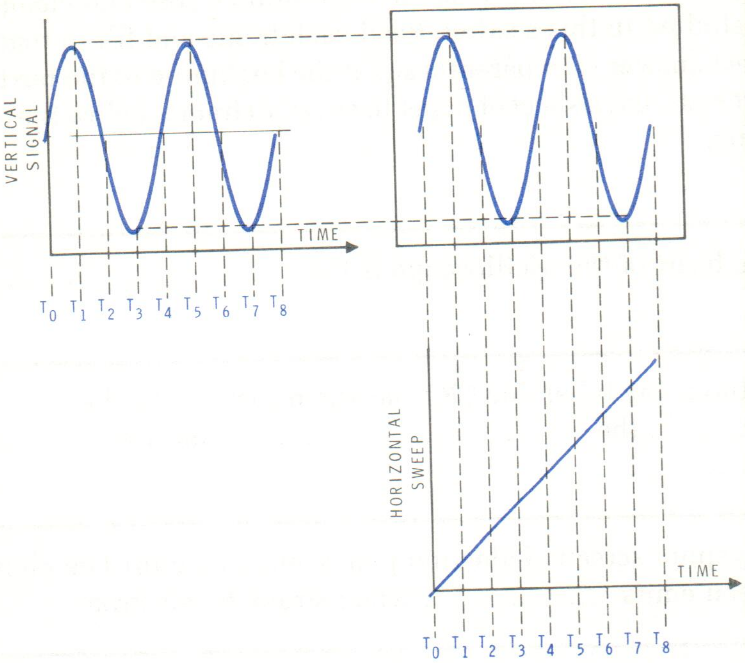

VERTICAL SIGNAL
TIME
T_0 T_1 T_2 T_3 T_4 T_5 T_6 T_7 T_8
HORIZONTAL SWEEP
TIME
T_0 T_1 T_2 T_3 T_4 T_5 T_6 T_7 T_8

Figure 18

Programmed Review

This programmed review is designed to reinforce your knowledge of the material studied in this section. Read each frame and fill in that frame. The correct answer is in parentheses at the beginning of the next frame. For best results, use a sheet of paper to cover all frames below the one you are reading.

1. The heart of the oscilloscope is the ________ ________ ________ .

2. (cathode ray tube) The CRT has three basic parts, the ________ ________, the ________ ________ and the ________ ________ .

3. (phosphor screen; deflection plates; electron gun) The phosphor screen emits ________ when struck by electrons.

4. (light) The ________ ________ provides a beam of high velocity electrons to the screen.

5. (electron gun) The energy given to the electrons by the electron gun is adequate at ________ frequencies.

6. (low) At higher frequencies, trace brightness will begin to ________.

7. (decrease) Therefore, some means of ________ ________ ________ is often used to speed up the electrons.

8. (post deflection acceleration) Two common methods of imparting post deflection acceleration are ________ and ________.

9. (helix; mesh) Another way to increase brightness without increasing acceleration is to ________ the screen.

10. (aluminize) An electron beam normally travels in a straight line; therefore, for the scope to be useful, some means must be provided to ________ the beam.

11. (deflect) The two methods of electron beam deflection are ________________ and ________________ .

12. (electromagnetic, electrostatic) The method most commonly used in oscilloscopes is the ________________ .

13. (electrostatic) Within the CRT, there are both ________________ and ________________ deflection plates.

14. (horizontal, vertical) The voltage that must be applied to the plates to deflect the beam a given amount is known as ________________ ________________ .

15. (deflection sensitivity) The vertical deflection plates are ________ (more/less) sensitive than the horizontal deflection plates.

16. (more) When the voltage on one of a pair of deflection plates is made more positive, the voltage on the other must be ________________ .

17. (more negative) When the voltage on the horizontal deflection plates is varied such that the electron beam moves back and forth across the screen, the result is known as a ________________ .

18. (sweep) The beam should be kept moving across the screen because if it is left in one spot too long, the phosphor may _____.

19. (burn) A varying voltage applied to the horizontal plates will draw a ________________ line on the screen, while a varying voltage applied to the vertical deflection plates will draw a ________________ line on the screen.

20. (horizontal; vertical) Thus, it is possible to compare the ________________ signal with the ________________.

(vertical; sweep or horizontal signal)

OSCILLOSCOPE CIRCUITS

Figure 19 is a block diagram of a basic oscilloscope. It contains the cathode ray tube with its vertical and horizontal deflection plates. These plates are driven by amplifiers which increase the input from as low as 1 mV to a value that will cause deflection.

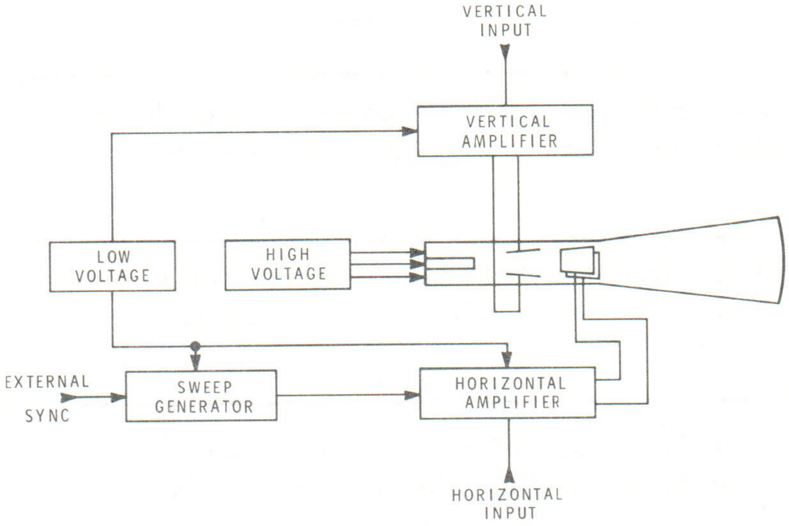


Figure 19

The horizontal amplifier has two inputs. One, from the sweep generator, is used to produce a horizontal trace across the screen. The other allows an external input to be displayed on the horizontal axis.

The vertical amplifier has only one input. The signal to be displayed is applied to this input. Thus, a quantity can be compared to an internally generated sweep or to another external input on the horizontal plates.

Sweep Generator

We have seen that a sweep is a horizontal trace on the face of the CRT that occurs in a selected period of time. The sweep generator generates a waveform that increases at a linear rate with respect to time until it reaches a predetermined value, at which time it suddenly drops to zero. It is this waveform that produces the horizontal trace or sweep on the CRT.

A basic sweep generator is shown in Figure 20. We will start our study with the switch closed. There will be no charge on the capacitor. As soon as the switch is opened, the capacitor will start to charge toward battery voltage. At first, C will charge at a linear rate. (See Figure 13B.) Therefore, if the switch is closed after a very short time, the capacitor will never reach the non-linear portion of its charge curve. Opening and closing the switch at the proper time will produce a continuous sawtooth of voltage.

Of course, it is impossible to operate a manual switch at the speed required by an electronic circuit. So, there is more to a practical sweep generator than is shown here.

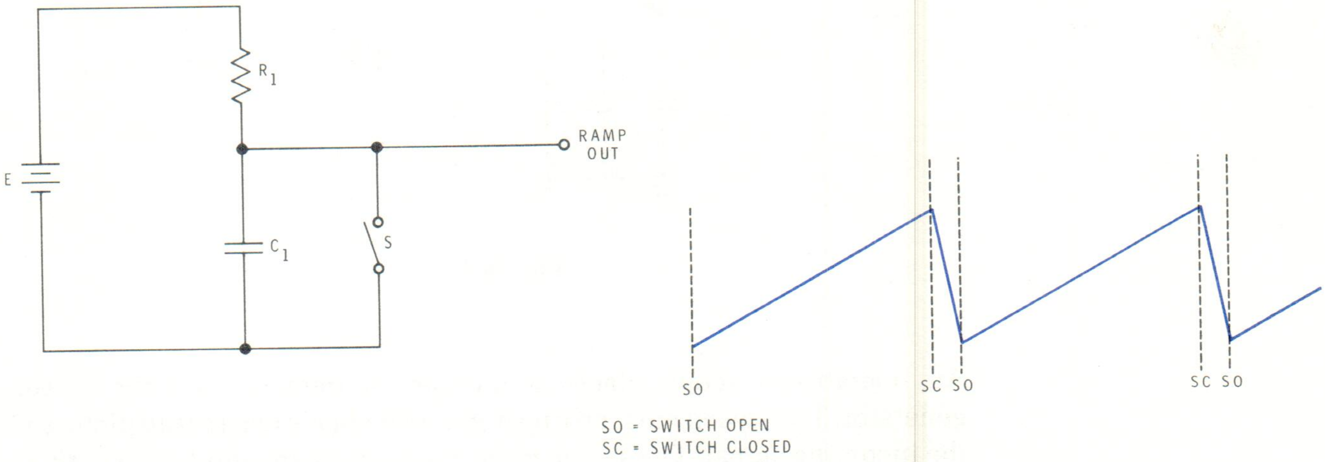


Figure 20

Figure 21 is similar to the ramp generator portion of the sweep generator circuits in a current Heathkit oscilloscope. When power is applied to the circuit, C begins to charge through Q1. Q1 is a constant current source that insures that C charges at a linear rate. During this time, Q2 is cut off, allowing the full charge on C to be felt at the ramp out. The ramp voltage is also applied to IC1 where it is compared to a pre-determined reference voltage. When the two are equal, a positive voltage is applied to the base of Q2, causing it to conduct and discharge C. Q2 corresponds to the switch in Figure 20. Thus, C discharges through Q2, which is almost a short circuit, giving a very fast discharge rate. Therefore, we have produced a ramp with a controlled rise time and a very short fall time. When the charge on C falls below a given level, forward bias is removed from Q2, starting the cycle all over again.

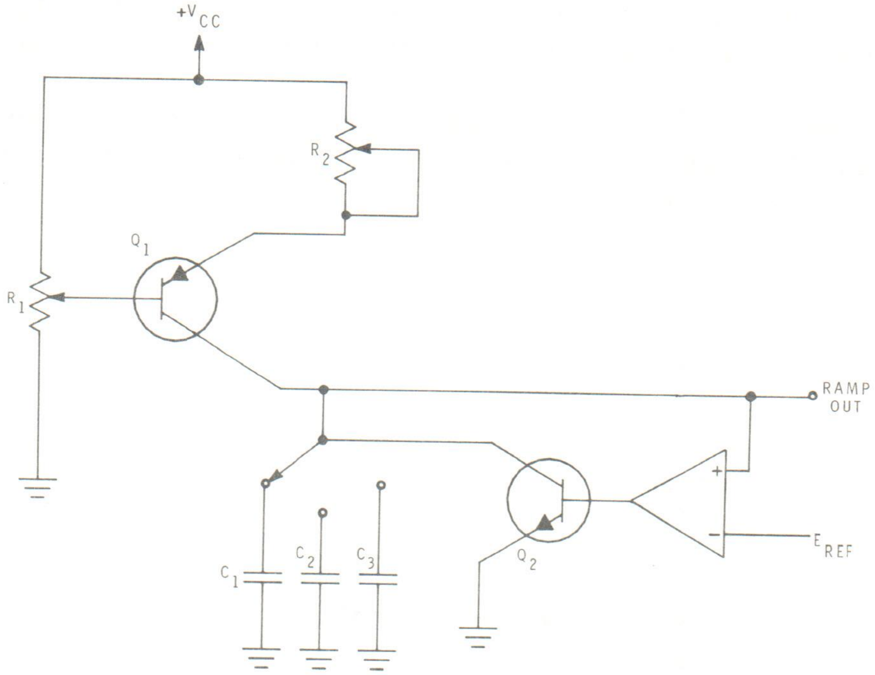


Figure 21

An operational scope places a number of demands on the sweep generator. The sweep must be linear if the display is to be a true picture of the incoming signal. The sweep must have a constant amplitude with no varying change in sweep time. The operator must also be able to control the sweep time when measuring frequency.

The precise control of the time it takes the sweep to move across the screen establishes a time base. It is this time base which allows the measurement of pulse width, pulse recurrence time, period of a waveform, etc. The time base will be calibrated in seconds per division. In almost all modern scopes, a division is equal to one centimeter. Thus, the calibration will read TIME/CM or SEC/DIV.

If the scope is to allow measurements over a wide range of frequencies, there must be some means of varying the time base. A common method is by switching to a different value of capacitance, as shown in Figure 21. In fact, anything that changes the charging current will change sweep time. Thus, we could also change sweep time by changing the resistance of R2 in Figure 21.

If an arrangement similar to that in Figure 21 is used, two types of control are available. There is a calibrated step control by switching capacitors and an uncalibrated vernier control by varying R2. Later, in the section on oscilloscope operation, you will learn how these controls are used.

Blanking and Unblanking

In looking at the sweep waveform (Figure 20), we see that the sweep goes slowly positive then rapidly negative. During the positive-going portion of the waveform, a horizontal trace is drawn on the screen from left to right. This portion of the signal has the proper timing as selected by the TIME/CM control.

At the end of the positive-going portion of the sweep, the voltage returns rapidly to its original level. In so doing, the electron beam will move from the right side of the screen to the left side. Unless some action is taken to prevent it, this **retrace** will be visible on the screen. It is undesirable to have a visible retrace; therefore, some means must be provided to **blank** the scope during retrace time.

In the section on CRT, you learned that the intensity of the electron beam can be controlled by controlling the voltage between the cathode and the control grid (G1) of the CRT. As the control gird is made more negative with respect to the cathode, the trace will become dimmer. When a sufficiently negative voltage is applied to the grid, the beam will be completely cut off, and the screen will be blank.

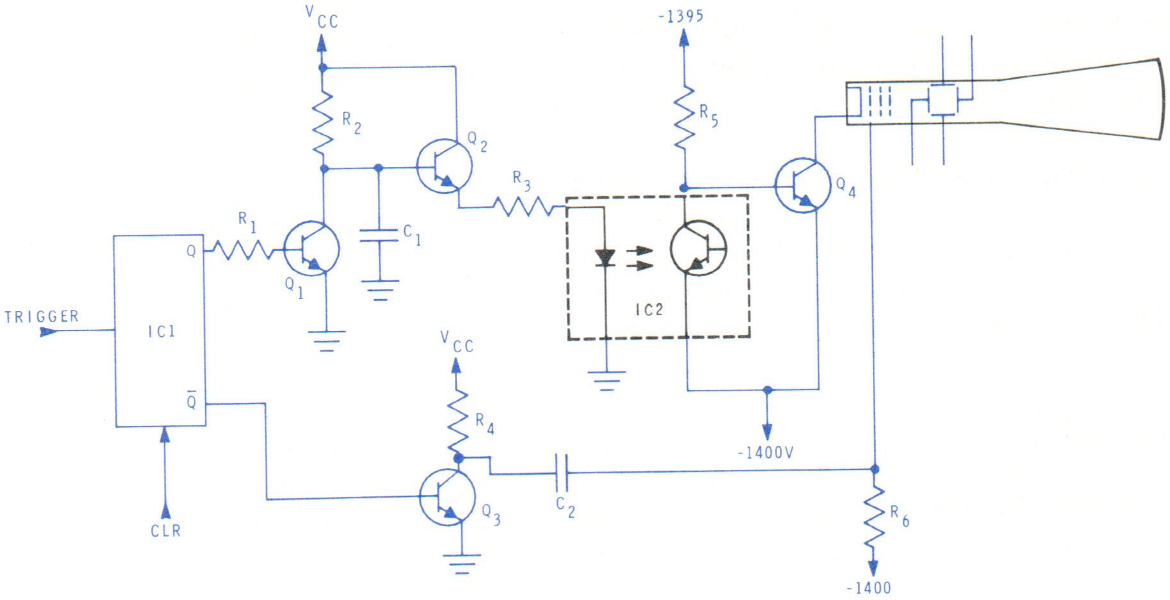


Figure 22

There are two ways to blank and unblank the CRT. The potential on the grid can be controlled or the potential on the cathode can be controlled. One Heathkit scope controls both. A simplified schematic of the blanking circuitry of this scope is shown in Figure 22.

IC1 is a J-K flip-flop which is set by the sweep trigger. We will discuss triggering later. When the flip-flop is set, the Q output is high and the $\overline{Q}$ output is low. With a high at Q, a positive voltage is applied to the base of Q1, causing it to conduct. This places the base of Q2 at essentially ground potential, holding it cut off. With Q2 cut off, no current flows through the diode portion of IC2.

IC2 is an optical isolator which consists of a light-emitting diode and a photosensitive transistor. As we know, a light-emitting diode emits light when it conducts, and a photosensitive transistor conducts when exposed to light. The arrangement is such that there is no electrical connection between the two. In this case, the optical isolator is used to isolate the high negative voltage of the cathode from the low voltage of the timing circuits.

If the diode portion of IC2 is drawing no current and emitting no light, Q4 will have −1395 V on the base and −1400 V on the emitter. Q4 is thus forward biased, which will allow cathode current to flow from −1400 V through Q4 to the cathode, through the CRT to the aquadag coating, back to the power supply. Thus, the cathode is **unblanked** during sweep time.

The $\overline{Q}$ output of the J-K flip-flop, which is low, is applied to the base of Q3, cutting off the transistor and causing the collector to go high. This high is coupled through C2 to the grid of the CRT, unblanking the CRT. Obviously, since this voltage is coupled through C2, it will start to decrease immediately. Therefore, unblanking the grid will only be effective for a short period of time. However, it is not necessary for the grid to be high in order for the tube to conduct. It is only necessary that it not be significantly more negative than the cathode.

We have seen how the CRT is unblanked during sweep time. Now, let's see how the blanking is accomplished. When the sweep voltage reaches a given value, a pulse is applied to the clear input of the J-K flip-flop. This resets the flip-flop, causing $\overline{Q}$ to go **high** and Q to go **low**.

When $\overline{Q}$ goes high, it causes the collector of Q3 to go low. This low is coupled through C2, driving the grid negative and blanking the CRT. As we saw previously, grid blanking as used here will only last for a short period of time. However, at the same time, $\overline{Q}$ went **high,** Q went **low**.

The low on Q drives Q1 to cutoff. The collector of Q1 will attempt to go high but will be delayed by a predetermined time by the RC time of R2 and C1. When C1 has charged to the necessary positive potential, Q2 will conduct, causing current to flow through the diode section of the optical isolator, IC2. This will cause light to strike the photosensitive transistor, allowing it to conduct. When the photosensitive transistor conducts, it places −1400 V on the base of Q4. With the same potential on both base and emitter, Q4 will cut off. Thus, no current can flow and the CRT is blanked.

Of the two blanking systems just discussed, the cathode circuit takes care of low frequencies of less than 60 Hz. The values of R2 and C1 are selected so that Q4 will never cut off at frequencies above 60 Hz. At these higher frequencies, all blanking is accomplished in the grid circuit.

We have shown you how blanking is accomplished in one Heath oscilloscope. There are many techniques used to blank a CRT. The important point is that the electron beam must be cut off during retrace time and turned on during sweep time.

Triggering

We mentioned earlier in this lesson that the sweep was started by a trigger. This is usually the case in modern scopes, but it is not universal. There are basically two types of sweep: the triggered sweep and the recurring or free-running sweep. Let's first look at the recurring sweep.

In the recurring mode, the sweep waveform will be as shown in Figure 23. The voltage will rise to maximum, drop back to the starting point, rise to maximum, etc. as long as power is applied to the circuit. The electron beam will sweep from left to right, retrace, sweep, retrace, etc.

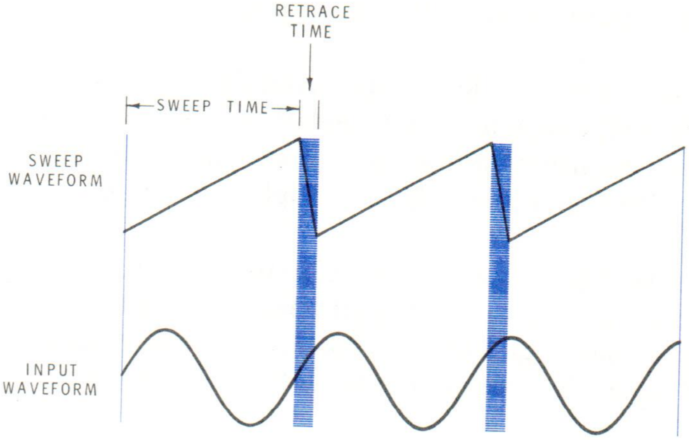


Figure 23

Suppose we wish to view a waveform, the period of which is exactly equal to sweep length. This waveform, a sine wave, is drawn to scale in Figure 23. Remember that we will display the portion of the sine wave that occurs during sweep time and blank out the portion that occurs during retrace time. Thus, during each sweep time, the portion of the input sine wave that occurs during that time will be displayed. Figure 24 shows how the display will appear with this input. The waveform shown here contains only three repetitions. Imagine what the display would look like with a large number of sweep cycles.

From this, we can deduce that for a display to be meaningful, the input waveform for each sweep must be identical to the previous one. In other words, each waveform must be superimposed on the one before. With the recurring sweep, this will occur only if the period of the incoming signal is an exact multiple of the sweep time plus the retrace time. Thus, we can see that it is impossible to view **one** complete cycle of the incoming

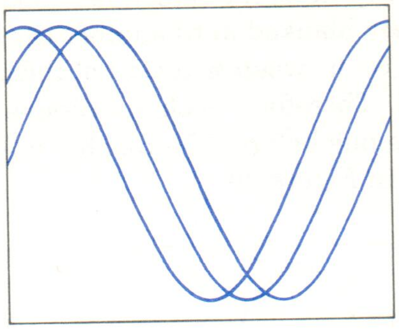


Figure 24

signal. It is also very difficult to synchronize or stabilize the display. If there is only a small difference between the incoming frequency and the sweep frequency, the display will appear to drift across the screen.

All of these problems can be cured by using a triggered sweep. A triggered sweep does not start until triggered. The most common method is to use the incoming signal to generate a trigger which starts the sweep.

Figure 25 shows how this works. When the incoming signal goes more positive than the trigger level, a trigger pulse is generated. The trigger pulse in turn starts the sweep generator. The sweep time can be whatever time the operator selects. In this case, it is equal to the period of one cycle of the input.

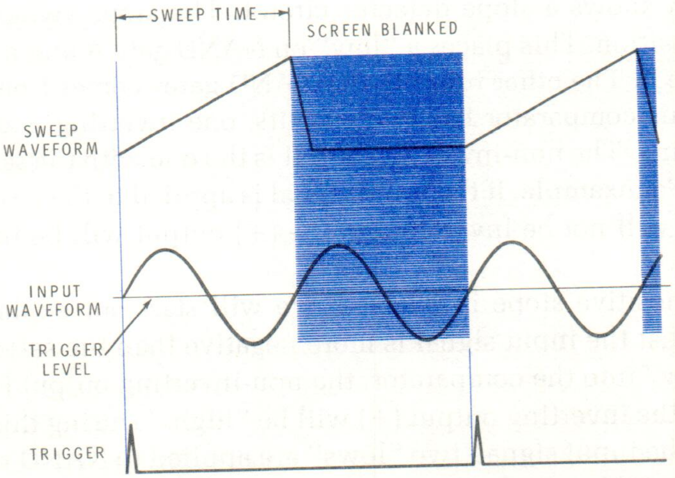


Figure 25

At the end of the sweep time, the screen is blanked and retrace occurs. The screen will remain blanked until another trigger is generated. With the triggered sweep, each sweep will start at the same relative point on the incoming signal. Therefore, each successive presentation will be superimposed on the one before. The display will appear as a distinct waveform as shown in Figure 26.

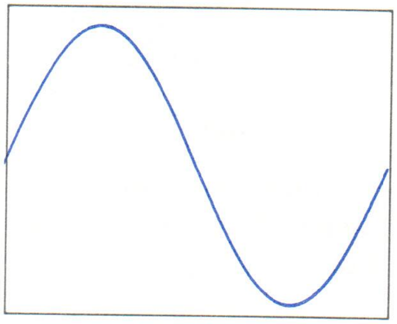


Figure 26

In this case, one complete cycle of the input waveform is shown. By varying the sweep time, it is possible to view a part of a cycle or any number of cycles.

The example in Figure 25 shows the trigger being generated when the input goes more positive than the trigger level. This is known as "triggering on the positive slope." Most scopes also have provisions for triggering on the negative slope, which means generating a trigger when the input goes more negative than the trigger level.

Figure 27A shows a slope detector circuit. The slope switch is in the positive position. This places a "low" on NAND gate A and a "high" on NAND gate B. The other input to the NAND gates comes from the comparator. This comparator has two outputs, one inverting and the other non-inverting. The non-inverting output is the one with the same sign as the input. For example, if the input signal is applied to the (−) input, the (−) output will not be inverted and the (+) output will be inverted.

Since the positive slope is selected, we will start our explanation by assuming that the input signal is more negative than the selected level. With a "low" into the comparator, the non-inverting output (−) will be "low" and the inverting output (+) will be "high." During this negative portion of the input signal, two "lows" are applied to NAND gate A; the output of A will be "high." At the same time, two "highs" are applied to the input of NAND gate B; the output of B will be "low." This places a "high" and a "low" on the input of NAND gate C; the output of C will be "high."

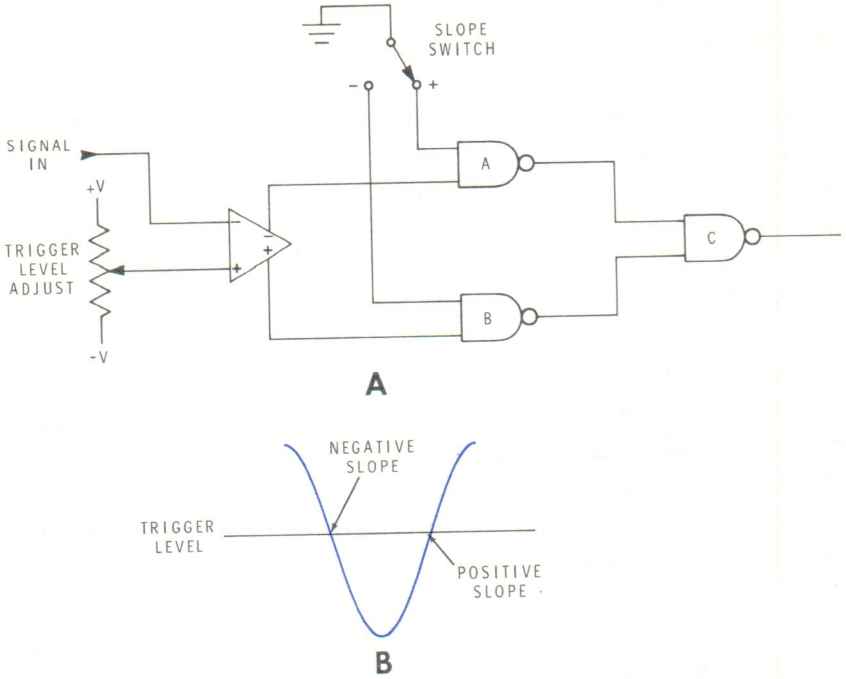


Figure 27

When the "signal in" passes through the trigger level in a positive direction, the outputs from the comparator will change. The non-inverting input will go "high" and the inverting input will go "low." This places a "high" and a "low" on A; the output of A remains "high." It also places a "high" and a "low" on B, causing the output of B to go "high." There are now two "highs" at the input of C; therefore, the output of C will go "low." When the output of C goes "low" a trigger will be generated which starts the sweep.

If the slope switch is placed in the (−) position, the same sort of action takes place. The difference is that the output of NAND gate C will be "low" when the **signal in** crosses the trigger level in a negative direction.

The major advantage of (+) and (−) triggering is that it allows the viewing of either the positive or negative portion of the input signal. A portion of the waveform can thus be expanded to better evaluate small portions.

Amplifiers

At least two very important oscilloscope specifications – bandwidth and sensitivity – are determined primarily by the amplifiers in the scope. It was mentioned earlier that the deflection sensitivity of a typical CRT was about 10 V/cm in a vertical direction and about 20 V/cm in the horizontal direction. Since the quantity to be measured or the output of the sweep generator is sure to be less than the amount required for sufficient deflection, amplification is required. Since amplitude is usually measured in the vertical channel, the vertical amplifier will be covered first.

SENSITIVITY

Vertical sensitivity is a measure of the amount of input voltage required to deflect the beam a given amount in a vertical direction. The amount of deflection is usually one centimeter. Thus, if 20 mV is required for 1 CM of deflection, the sensitivity would be stated as 20 mV/CM, or perhaps just 20 mV. Obviously, a scope which requires 5 mV to deflect the beam 1 division is more sensitive than one that requires 20 mV.

Since oscilloscope voltage measurements are peak-to-peak measurements, one might expect that sensitivity would always be given in peak-to-peak volts-per-division. However, this is not the case. It is fairly common to see sensitivity specifications given as an RMS value. Remember, that peak-to-peak (P-P) is equal to 2.828 times RMS; therefore, the RMS figure must be multiplied by 2.828 to obtain the P-P figure. In other words, a scope that has a rating of 5 mV RMS will give one division of peak-to-peak deflection with an input of 5 mV RMS or 14.14 mV P-P. Thus, a scope with a sensitivity rating of 20 mV RMS is not as sensitive as one with a sensitivity rating of 50 mV P-P.

Sensitivity is very important when working with modern communications equipment. Signal voltages of 10 mV P-P or less are common. To display a 10 mV P-P waveform at a size suitable for proper interpretation requires a deflection of at least 2 divisions. Thus, a 5 mV/DIV sensitivity is required.

Some of the signals require a low-capacity probe to avoid loading the circuit or distorting the waveform. The low-capacity, or passive, probe is normally a ×10 probe. This probe attenuates the signal by a factor of 10. Thus, if a 10 mV P-P signal is to give two divisions of deflection, a 1 mV/DIV sensitivity is required.

Some of the more expensive scopes have a vertical expander, or magnifier, either ×5, or ×10, or both. The expander increases the effective sensitivity by a factor of 5, or 10, or whatever it is. Therefore, a scope with a sensitivity of 10 mV/CM and a ×5 magnifier has an effective sensitivity of 2 mV/CM.

On many scopes, when the expander is used, the bandwidth is decreased. Expansion by a factor of 5 reduces the bandwidth by a factor of 2. A ×10 expansion reduces bandwidth by a factor of 4. Thus, a scope might have a bandwidth of 20 MHz without expansion and 5 MHz with a ×10 expansion. Other scopes may not have an expander labeled as such but may reduce the bandwidth at the higher sensitivity.

Sensitivity means the ability to measure low voltages.

Measuring high voltages can be just as important as measuring low voltages. All of the in-between voltages are important too; so all scopes have some form of input attenuator. Usually, this will be a step attenuator with the steps calibrated to indicate the vertical sensitivity. The attenuation is usually stepped in a 1-2-5 sequence. Thus, the **VOLTS/DIV** switch on a good oscilloscope might read, 1 mV, 2 mV, 5 mV, 10 mV, 20 mV, etc. up to a maximum of 10 V, 20 V, or 50 V. If the maximum **VOLTS/DIV** setting is 20 V, full deflection of 8 divisions is utilized and a ×10 probe is used, a maximum voltage of $20 \times 8 \times 10 = 1{,}600$ volts can be measured. This is usually more than enough.

Sometimes it is desirable to set the vertical deflection to a fixed amount. Usually this is done when a comparison between values is more important than the actual value. Most scopes include a **VARIABLE** control for just this purpose. This control will have a calibrated or **CAL** position, which is normally at the fully clockwise position. In the **CAL** position, the setting of the **VOLTS/DIVISION** control are usually accurate within ±3 to 5 percent. With the **VARIABLE** control out of the **CAL** position, the height of the waveform is continuously variable, usually between two adjacent attenuator values. Normally, the signal size will be reduced as the **VARIABLE** is rotated counterclockwise.

BANDWIDTH

A vertical amplifier to meet the preceding requirements would be relatively simple if it were required to operate at only one frequency or even a narrow band of frequenices. However, this is not the case. An oscilloscope is often required to measure everything from a DC voltage to the RF output of a transmitter. Some scopes are capable of displaying a wider range of frequencies than others, depending on the vertical bandwidth of the oscilloscope. Bandwidth is a measure of the frequency range over which the oscilloscope faithfully displays the input waveform. Ideally, the vertical amplifier should amplify each frequency by the same amount. It is nearly impossible to obtain a perfectly flat amplification curve. Some frequencies are going to be amplified more than others. Normally, the manufacturer will keep the level within ±3 dB throughout the rated bandwidth. That means that the amplifier can have a voltage gain that varies from 0.7 to 1.4 times the nominal gain.

When looking at oscilloscope specifications, don't be misled by statements such as "usable to 30 MHz" or "down 3 dB at 10 MHz." The statements are no doubt true, but they leave some unanswered questions. What does usable mean and what happens between 0 Hz and 10 MHz? The type of specification you should be looking for reads "within 3 dB from DC to 10 MHz, DC to 5 MHz ±3 dB, or DC to 15 MHz (±3 dB)."

Beyond the rated bandwidth, there should be a 6 dB per octave rolloff rate. In other words, the amplitude should be cut in half everytime the frequency is doubled. Thus, sensitivity decreases and vertical calibration becomes less and less accurate as frequency increases.

It is possible to display a signal with a frequency above the bandwidth of the scope. Of course, you will be unable to measure the amplitude and the amplitude will be smaller than normal. If the waveform is other than a pure sine wave, it will have a particular harmonic content. Since the harmonics are at a higher frequency than the fundamental, they will be attenuated more. Therefore, the wave shape may not be displayed accurately.

In the section on CRT's, we mentioned that a given amount of deflection voltage is required at the deflection plates of the CRT. As frequency increased, more voltage was required. It is the responsibility of the vertical amplifiers to provide this voltage. At higher frequencies, the amplifiers will be unable to supply the necessary drive, and the display will be reduced in amplitude. Changing the sensitivity setting will have no effect, as the problem is lack of drive potential, not lack of input signal.

A typical oscilloscope will have a 3-position input switch; AC, DC, and GROUND. In the AC position, the DC component of the input signal will be blocked. However, the reactance of the capacitor will also attenuate the low frequency component of the signal. The −3 dB point for the low frequency end of the bandwidth usually occurs at between 2 and 10 Hz.

In the DC position, the signal is coupled directly from the input to the vertical amplifier, and there is no low frequency limit.

The GROUND position places the input at chassis ground and is normally used to establish a 0 V (zero-volt) reference for measuring DC voltages.

RISE TIME

Rise time (Tr), or how fast the vertical channel can react, is very closely related to bandwidth. Rise time is defined as the time required for a waveform to change from 10% of its maximum value to 90% of its maximum value as shown in Figure 28.

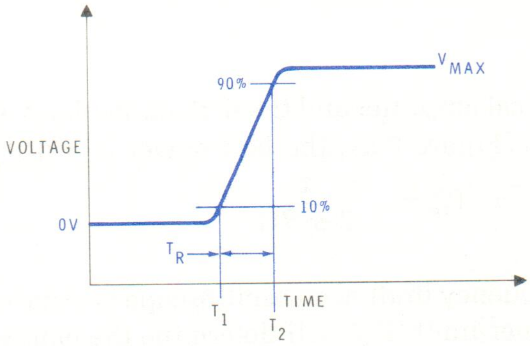


Figure 28

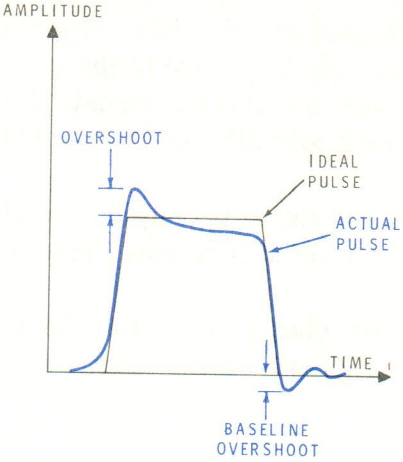


Figure 29

One would expect that a faster rise time would be better. However, this is not always the case. Unless the vertical amplifier has sufficient bandwidth, too fast a rise time may cause distortion in the form of overshoot as shown in Figure 29. The ideal pulse shape is shown in black and the actual pulse shape is shown in blue.

Some amount of overshoot is inevitable. Therefore, a compromise must be made. The best trade off occurs when rise time multiplied by bandwidth equals approximately 0.35. Thus, given the required rise time, the necessary bandwidth can be calculated by the formula

$$BW = \frac{0.35}{T_r}$$

If we view the vertical amplifier and the deflection plates as a simple RC circuit as shown in Figure 30A, the half-power (−3 dB) point can be found by the formula $F_{co} = \frac{1}{2\pi RC}$

Since the lower frequency limit of an oscilloscope is usually extended to DC or 0 Hz, the upper limit (F_{co}) will determine the bandwidth (Figure 30B). Therefore, we can substitute BW for F_{co} and arrive at

$$BW = \frac{1}{2\pi RC}$$

with R being the effective resistance of the amplifier and C the capacitance of the deflection plates.

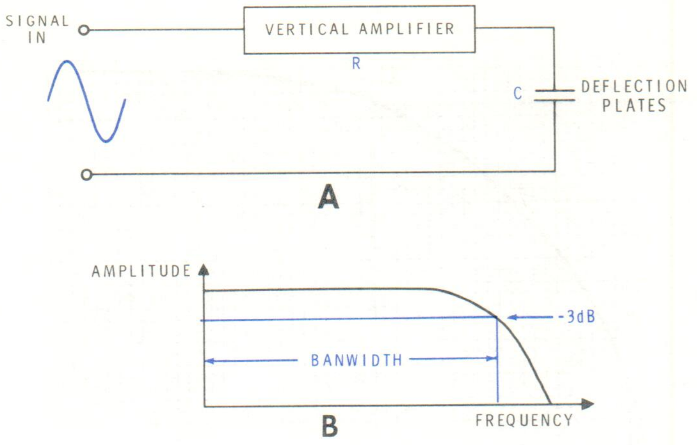


Figure 30

Still using the RC circuit analogy, but this time considering the time domain instead of the frequency domain, we see that with a square wave applied, a certain period of time is required for the plates to charge (Figure 31A). We have already defined rise time as being the time required for the plate voltage to change from 10% of maximum to 90% of maximum. Therefore, we can see that rise time (T_r) can be found by $T_r = t_2 - t_1$ (Figure 31B).

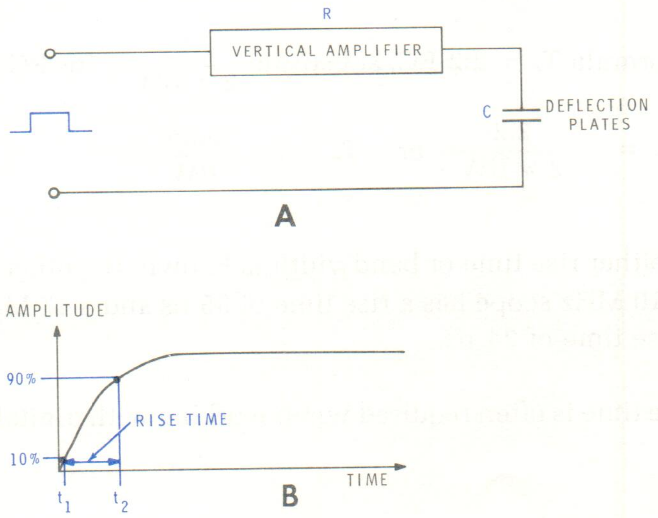


Figure 31

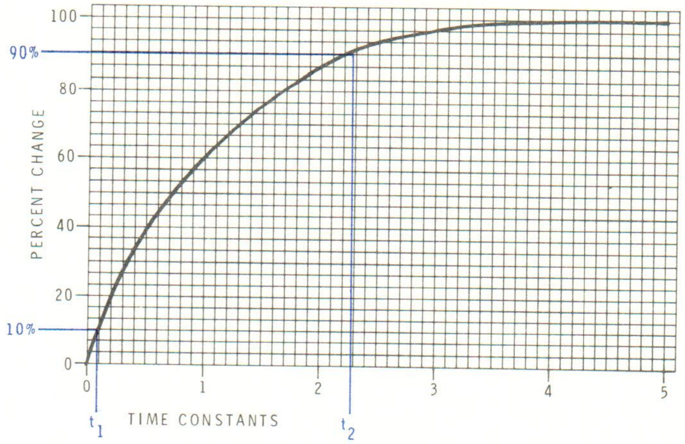


Figure 32

Looking at the universal time constant chart (Figure 32) we see that $t_2 - t_1$ is equal to 2.2 time constants. We know from previous lessons that one time constant is equal to the product of R times C. Thus, $T_r = 2.2\ RC$.

If the formula $BW = \frac{1}{2\pi RC}$ is solved for RC, we have

$$RC = \frac{1}{2\pi BW}$$

In the formula $T_r = 2.2\ RC$, substitute $\frac{1}{2\pi BW}$ for RC and we have

$$T_r = \frac{2.2}{2\pi BW} \quad \text{or} \quad T_r = \frac{0.35}{BW}$$

Thus, if either rise time or bandwidth is known, the other can be calculated. A 10 MHz scope has a rise time of 35 ns and a 15 MHz scope will have a rise time of 24 ns.

A fast rise time is often required when working with digital equipment.

A desirable situation is to have the rise time of the scope 1/5 or less of the rise time of the waveform being measured. A rise time of 10 ns is adequate for most applications. From the preceding information, we can see that this requires a scope bandwidth of 35 MHz. Some digital circuits have very fast rise times. It is fairly common to have rise times of less than 20 ns. A signal rise time of 17.5 ns requires a scope rise time of 3.5 ns, which means a bandwidth of 100 MHz.

This does not mean that you cannot use your scope to measure rise time just because it is slow. It does mean that you cannot read the rise time directly from the scope. You will have to perform some calculations. Suppose you are measuring the rise time of a square wave, using a 15 MHz scope with a rise time (T_{rs}) of 24 ns. You find that the displayed rise time (T_{rd}) is 40 ns. You don't take the difference between the two. Total rise time is a sum of the squares.

$$T_{rd}^2 = T_{rg}^2 + T_{rs}^2$$

Solving for T_{rg}, we get $T_{rg}^2 = T_{rd}^2 - T_{rs}^2$

or $T_{rg} = \sqrt{T_{rd}^2 - T_{rs}^2}$

$= \sqrt{40^2 - 24^2}$

$= 32$ ns.

Rise times **do not** simply add together.

Power Supply

In a high quality oscilloscope, the power supply is a very important part of the overall unit. To help you understand some of the reasons this is true, let's look at the incoming AC line voltage. Sometimes, a normal voltage of 115 V will vary from as low as 90 V up to as high as 130 V.

If these changes are allowed to influence the internal scope voltages, several things happen. For one, the length of the sweep is affected by the supply voltage to the sweep generator. If a shorter or longer sweep is generated in the same time as the normal sweep, the TIME/CM will change. This will cause an error in any time or frequency measurement.

Brightness and focus may also be affected. Without proper regulation, the grid voltages on the CRT change with the input voltage, thus causing the trace to grow brighter or dimmer.

Vertical calibration may also change unless the regulation is good. There are two ways that this may be affected. We already know that the acceleration voltage may change, causing a corresponding change in the speed of the electron beam. A slower electron will spend more time in the vicinity of the deflection plates, and thus be deflected more, while a faster electron will pass through the plates faster with less deflection. Thus, the acceleration voltage affects both vertical and horizontal sensitivity.

The supply voltage to the horizontal and vertical amplifiers will affect their amplification and, therefore, the size of the signal applied to the deflection plates.

Any effective method may be used to regulate the power supply voltages for an oscilloscope. However, it is essential in a quality scope that adequate regulation be maintained.

Programmed Review

21. The voltage to the horizontal and vertical deflection plates is provided by the horizontal and vertical ________.

22. (amplifiers) The horizontal amplifier usually has inputs from an internal ________ ________ and from an external ________ .

23. (sweep generator; source) The basic sweep is a ramp of voltage with a controlled ________ time and a very short ________ time.

24. (rise; fall) The ramp or sweep must be ________ if it is to faithfully reproduce the input.

25. (linear) In order to measure frequency, the operator must have control of ________ ________.

26. (sweep time) The time it takes the sweep to transverse the screen is known as the ________ ________.

27. (time base) The time base is usually calibrated in ________/________.

28. (TIME/CM) In a versatile scope, this time base must be ________.

29. (variable) The time after a sweep is completed, when the electron beam is returning to the other side of the screen, is known as ________.

30. (retrace) Some means must be provided to ________ the CRT during retrace.

31. (blank) Blanking and unblanking is accomplished by controlling the potential between the ________ and the ________.

32. (cathode and grid) A means must also be provided to control the sweep start time. This control is called ____________.

33. (triggering) When triggering is not provided, the sweep is ____________.

34. (recurrent or free-running) Triggering helps to ____________ the display on the screen.

35. (stabilize) A portion of the ________ ________ is normally used to trigger the sweep.

36. (incoming signal) Two primary specifications that are determined primarily by the amplifiers are ____________ and ____________.

37. (bandwidth, sensitivity) The sensitivity determines the ____________ signal that can be measured on the scope.

38. (smallest) One method of increasing sensitivity is by the use of vertical ____________.

39. (magnifiers) Provision is made for measuring high voltages by use of an ____________.

40. (attenuator) The specification that determines the maximum frequency that can be measured is ____________.

41. (bandwidth) Bandwidth is directly related to how well the vertical amplifier responds to a rapid change in voltage. This response is known as ________ ________.

42. (rise time) Rise time is a measure of how long it takes the waveform to change from ____% of maximum to ____% of maximum.

43. (10; 90) In order for the oscilloscope circuits to work properly, the power supply must be well ____________.

(regulated)

SPECIAL FEATURES

The oscilloscope that we have been discussing is adequate for a large portion of electronic work. However, there are times when we would like to extend this capability. There are many special features available that allow certain parameters of the oscilloscope to be expanded.

The magnifier and the delayed time base allow for more detailed inspection of a selected portion of the trace. The dual beam or dual trace oscilloscope permits the operator to view two signals at the same time. The sampling oscilloscope allows extremely high frequency signals to be displayed while the storage oscilloscope displays very slow signals.

Magnifier

The magnifier or expanded sweep is a very common feature and is found on most moderately-priced and high-priced scopes. The purpose of the magnifier is to enlarge a portion of the waveform for closer observation. The most common method of magnification is to make the sweep longer — usually, by a factor of 5 or 10.

In Figure 33A, we see an oscilloscope presentation as it would normally appear. The sweep is physically ten divisions long. It is obvious that little information can be obtained about the pulse except for pulse width (PW) and pulse recurrence time (PRT). To see more detail of the wave shape, we must expand the waveform.

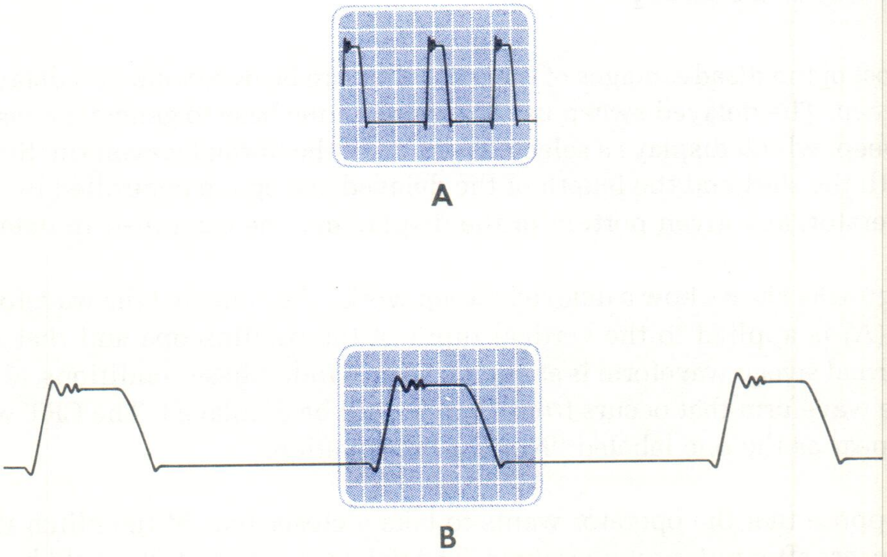


Figure 33

Figure 33B shows the same waveform with a ×5 expansion or magnification. The length of the sweep has been increased from ten divisions to fifty divisions. The sweep time remains the same, only the length is changed. If a **TIME/CM** of 2 μS is selected, the presentation in Figure 33A will require 20 μS. The entire waveform in Figure 33B also requires 20 μS; however, the presentation in Figure 33B — the portion visible on the screen — requires 4 μS.

By using the horizontal position control, the waveform can be moved until any 4 μS portion is visible on the CRT. Thus, we have effectively increased the sweep speed of a selected portion of the waveform.

The same results could not be obtained by changing the time-per-division control. That would only allow the first portion of the waveform to be expanded. Therefore, the second and third pulses would be "pushed" off the screen. Also, a portion of the leading edge of the first pulse will be lost. The amount that would be lost depends on the trigger level.

As useful as the magnifier is for viewing a particular section of waveform, it does have disadvantages. Since the magnification is obtained by increasing the gain of the horizontal amplifier, it is limited to about ×10. Even at a ×10 magnification, it is sometimes difficult to locate the exact portion of waveform to be displayed. Also, any errors in the magnification are added to the normal timing errors. Thus, the total timing error, when magnification is used, may approach 10%.

Delayed Sweep

Most of the disadvantages of the magnifier can be overcome by a delayed sweep. The delayed sweep uses a separate time base to generate a faster sweep, which displays a selected portion of the normal waveform. Since both the start and the length of the delayed sweep are controlled by the operator, any given portion of the display may be examined in detail.

Figure 34 shows how a delayed sweep works. Assume that the waveform at (A) is applied to the vertical input of the oscilloscope and that the normal sweep waveform is as shown at (B). Under these conditions, all of the waveform that occurs from T_0 to T_3 will be displayed. The CRT will appear as the one labeled "Normal Presentation."

Suppose that the operator wants to take a closer look at the glitch that appears after pulse number three. The delayed trigger start would be set to a point in time just before the glitch occurs. When the normal sweep

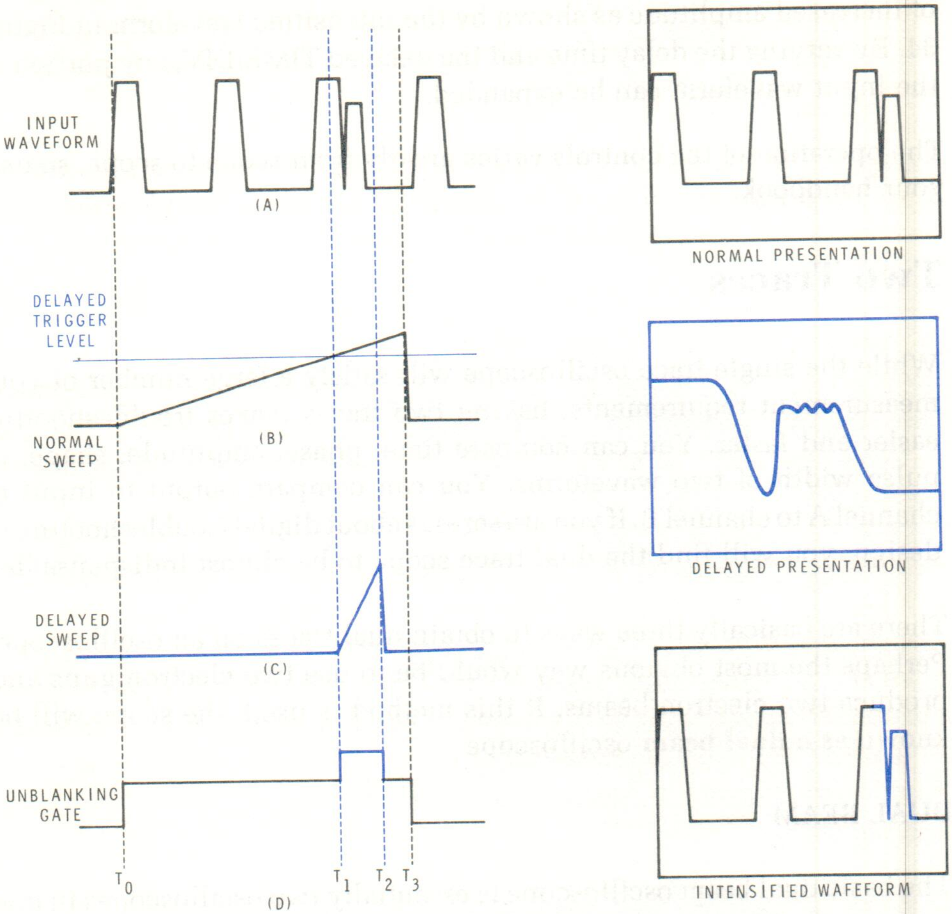


Figure 34

voltage passes through the delayed trigger level, a trigger is generated which starts the delayed sweep. A delayed sweep time is selected that will allow just the desired portion of waveform to be displayed. In this case, the delayed sweep time is between T_1 and T_2. Keep in mind that when delayed sweep is selected, the normal sweep is disconnected from the CRT and the delayed sweep circuits take over. Thus, the delayed sweep display will be similar to the one labeled "Delayed Presentation."

When using delayed sweep, which is often called delayed time base, locating the portion of the normal or main sweep presentation to be studied is quite simple. Provision is made for intensifying the normal presentation.

Remember that the intensity of the trace on the CRT is controlled by the potential difference between G1 and the cathode. If the unblanking gate (waveform D of Figure 34) is increased in amplitude from T_1 to T_2 and applied to the control grid (G1), the trace will be brighter during the time of increased amplitude as shown by the intensified waveform in Figure 34. By varying the delay time and the delayed TIME/DIV, any portion of the input waveform can be expanded.

The operation of the controls varies greatly from scope to scope, so use your handbook.

Two Traces

While the single trace oscilloscope will satisfy a large number of your measurement requirements, having two traces makes troubleshooting easier and faster. You can compare time, phase, amplitude, shape, or pulse width of two waveforms. You can compare output to input or channel A to channel B. If you are serious about digital troubleshooting or design, you will find the dual trace scope to be almost indispensable.

There are basically three ways to obtain dual traces on an oscilloscope. Perhaps the most obvious way would be to use two electron guns and produce two electron beams. If this method is used, the scope will be known as a **dual beam** oscilloscope.

DUAL BEAM

The basic dual beam oscilloscope is essentially two oscilloscopes in one as shown in Figure 35. The CRT contains two electron guns and two sets of deflection plates. Obviously, this is more expensive to build than a single beam CRT. There are also other disadvantages.

Because of the physical separation of the electron guns, the beams will not naturally strike the center of the CRT. Thus, both waveforms will be distorted somewhat. Each waveform will have something like a keystone shape as shown in Figure 36. Of course, the distortion is exaggerated, but the effect is enough to cause inaccuracies in measurement.

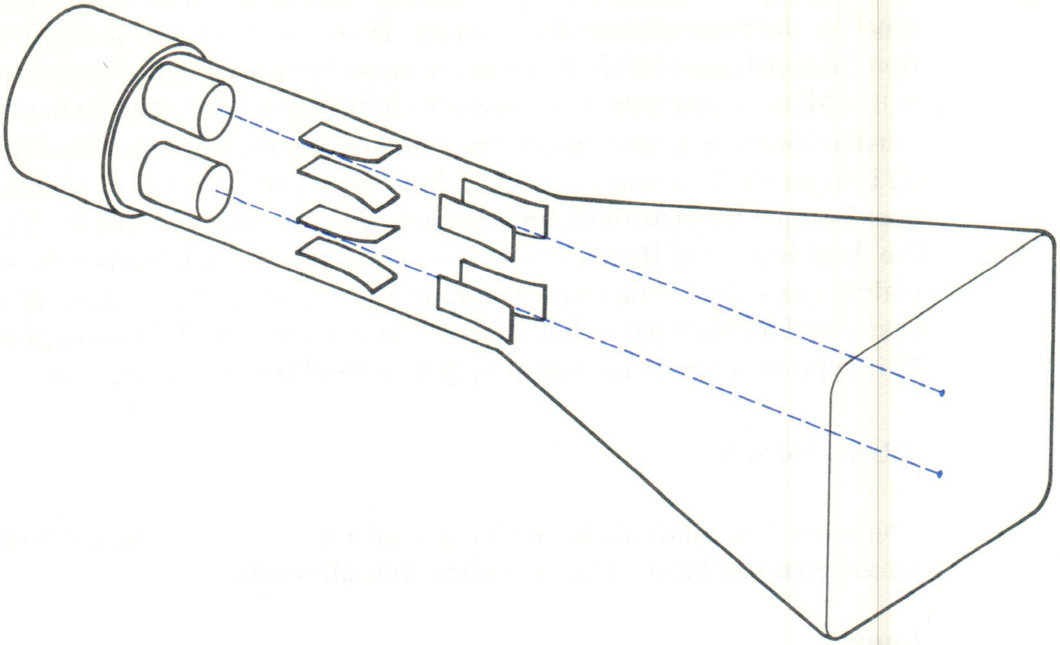


Figure 35

There are other disadvantages of a dual beam scope. For instance, if timing comparisons were to be made, the two horizontal deflection circuits would have to be perfectly in sync. This is impractical, especially at higher frequencies. Therefore, the two sets of horizontal deflection plates, amplifiers, and timing circuits were combined into one set. Then the two electron guns were moved closer together, until the final result was one gun with a split beam. This effectively eliminates the distortion caused by off-center gun placement. Thus, the typical **dual beam** scope has one set of horizontal components and two complete vertical channels.

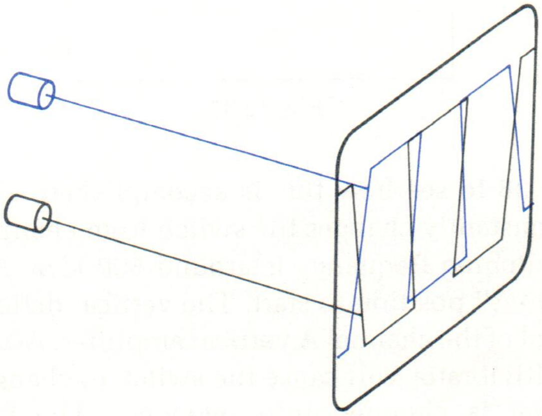


Figure 36

It would appear that the arrangement just discussed would be practically ideal for the presentation of two traces. There are, however, some limitations. As we learned earlier, one of the major features of a dual trace scope is its ability to compare. For accurate comparison, the vertical channels must be identical in gain, phase shift, and frequency response. This is not an impossible task and is, in fact, done on several scopes. However, it does become more difficult and expensive as frequency increases. Thus, the **dual beam** oscilloscope is quite expensive and relatively rare as a maintenance tool. The more common scope uses a single gun, single beam, and a single set of both vertical and horizontal deflection plates. This type of scope is known simply as a **dual trace** oscilloscope.

DUAL TRACE

There are two methods by which a dual trace can be obtained from a single electron beam. They are **chop** and **alternate.**

Chop

In the chop method of dual trace generation, the electron beam is "time shared" between vertical channels at a very rapid rate. With no input to the vertical channels, the CRT presentation will appear as in Figure 37. Here you can see where the name "chop" comes from. Each trace appears to be chopped into sections.

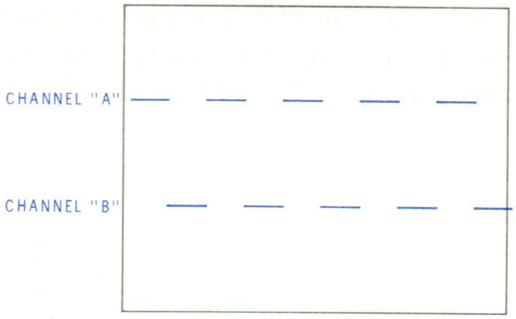


Figure 37

Refer to Figure 38 to see how this is accomplished. The free-running multivibrator constantly changes the switch from channel A to channel B. A typical switching frequency is around 500 kHz. Assume that the switch is in the "A" position to start. The vertical deflection plates are under the control of the channel A vertical amplifier. After a short period of time, the multivibrator will cause the switch to change to channel B. Thus, the sweep is chopped into segments. The first segment is

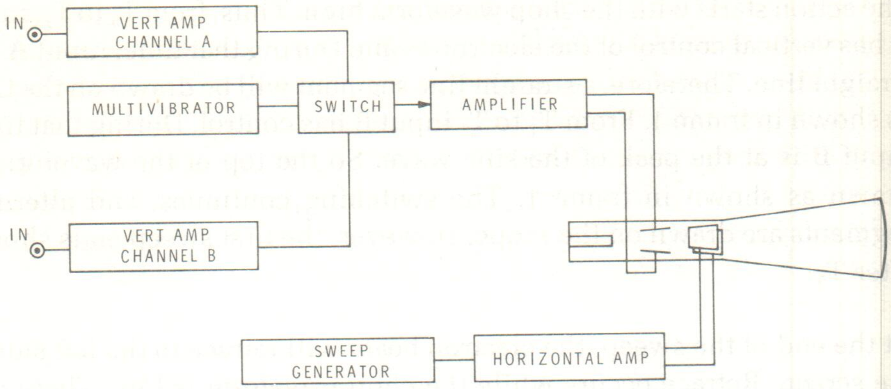


Figure 38

positioned vertically by channel A, the second by channel B, then A, then B, etc.

It might appear that a chopped waveform would cause viewing problems. However, this is rarely the case and only occurs when the chopping rate is an exact multiple of the input frequency.

In Figure 39, the input to channel A is a pulse, and the input to channel B is a sine wave. During the high portion of the chop waveform, channel A is connected to the vertical deflection plates, and during the low portion, channel B is connected. The sweep is repetitive and equal to the period of the sine wave.

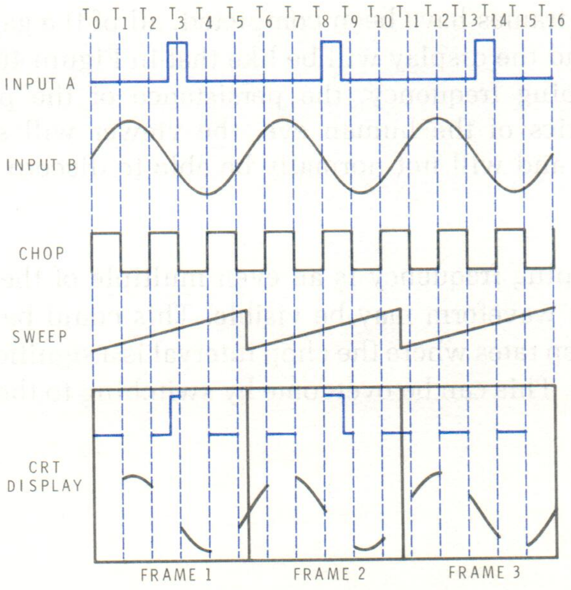

T_0 T_1 T_2 T_3 T_4 T_5 T_6 T_7 T_8 T_9 T_{10} T_{11} T_{12} T_{13} T_{14} T_{15} T_{16}
INPUT A
INPUT B
CHOP
SWEEP
CRT DISPLAY
FRAME 1
FRAME 2
FRAME 3

Figure 39

The action starts with the chop waveform high. Thus, from T_0 to T_1, input A has vertical control of the electron beam. During that time, input A is a straight line. Therefore, a straight line segment will be drawn on the CRT as shown in frame 1. From T_1 to T_2 input B has control. During that time, input B is at the peak of the sine wave. So the top of the waveform is drawn as shown in frame 1. The switching continues, and alternate segments are drawn on the scope. However, the first sweep ends shortly after T_5.

At the end of the sweep, the electron beam will retrace to the left side of the screen. Retrace occurs while the chop waveform is low. Therefore, when the beam returns to the left of the screen, it will continue drawing waveform B as shown at the start of frame 2.

We have shown a recurring sweep with instant retrace. You know that an instant retrace cannot happen. However, if it did, the effect would be the same as a triggered sweep. Therefore, we have shown it this way to simplify the explanation. The action continues as long as the inputs and sweep controls remain unchanged. However, three frames are suitable to show what happens.

If you could stop the action after one frame or sweep, you would see a display like that in Figure 40A. The persistence of the phosphor is such that what was drawn during frame 1 will still be there a few frames later. So, after two frames, the display will be a combination of frame 1 and frame 2 and will appear as in Figure 40B.

After three frames have been completed, all of the gaps will have been filled in, and the display will be like that in Figure 40C. Because of the high chopping frequency, the persistence of the phosphor and the characteristics of the human eye, the viewer will see two complete waveforms and will not normally be able to discern the different segments.

If the chopping frequency is an even multiple of the input frequency, gaps in the waveform may be visible. This could be a problem at the higher sweep rates where the chop interval is a significant portion of the sweep time. This can be overcome by switching to the **alternate** mode.

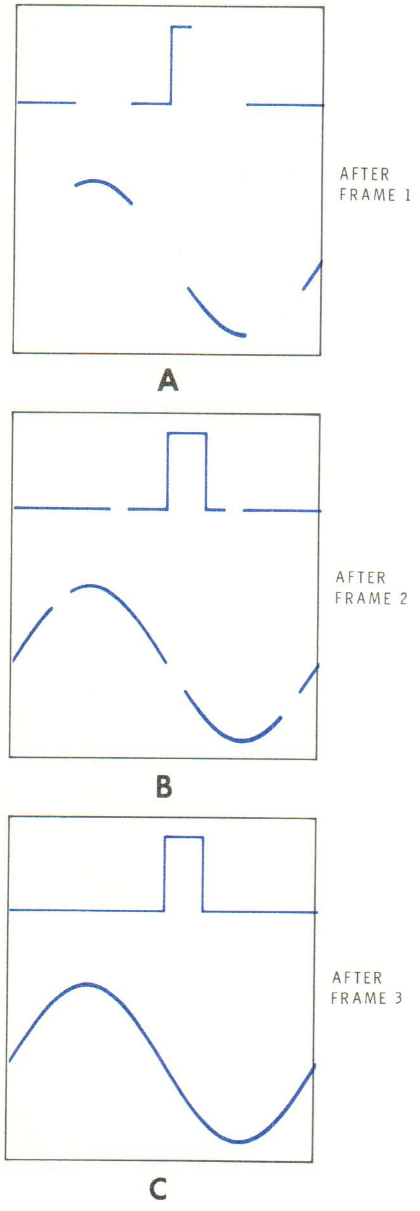


Figure 40

Alternate

In the alternate mode, the scope makes one complete sweep for channel A, then makes a complete sweep for channel B as shown in Figure 41. Here, when the alternating waveform is high, input A is fed to the vertical deflection plates, and when the alternating waveform is low, input B goes to the plates.

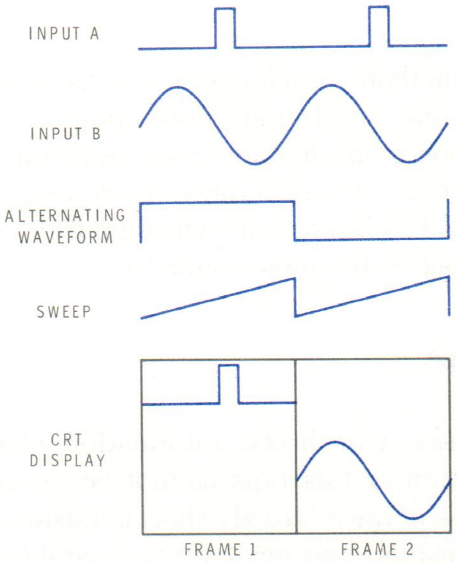


Figure 41

As the action starts, the alternating waveform is high and stays high for one complete sweep. Thus, during that time, only input A is fed to the CRT, and the display will be as shown in frame 1. During retrace time, the alternating waveform goes low so that, during the second sweep, input B is displayed as shown in frame 2. The display will then alternate between A and B continuously. To the operator, the display will appear as in Figure 40C.

If the alternate mode is used at low sweep rates, the operator will be able to discern first one trace, then the other. This can be very disconcerting. Therefore, it is normal operation to use the alternate mode at fast sweep rates and the chop mode at low sweep rates. In fact, some scopes will automatically switch from chopped to alternate at a predetermined point when sweep speed is increased and from alternate to chopped as speed is decreased. If a scope has either an alternate or a chopped mode, it will most likely have both so that the best mode for the measurement being made can be selected.

Summary

There are the three methods of achieving two traces on a scope. The dual beam method provides continuous presentation of both inputs. The chopped mode chops both channels into segments, and the alternate mode changes channels with each trace. As we have seen, each method has its advantages and its limitations. The **dual trace** scope offering both alternate and chopped is the most common.

Storage Scope

It is sometimes necessary to observe information which is not repetitive in nature. Information of this type cannot be viewed on a "normal" oscilloscope because of the relatively short persistence of the phosphor. Long persistence phosphors are available that would overcome this problem; however, they would introduce more serious problems. The long persistence would be unsuitable for the "normal" recurrent signal. Both types of signals can be accommodated by a specially constructed CRT known as a **STORAGE** CRT.

There are several types of storage CRT's available. They are used in radar, data transmission, medical equipment, and test equipment. The type most commonly used in test equipment oscilloscopes is the **variable persistence/storage cathode-ray tube.** This is the only one we will discuss here.

CONSTRUCTION

The basic construction of a storage CRT is shown in Figure 42. Notice that this CRT has all the standard components; electron gun, deflection plates, and phosphor coating. In addition to these, the storage CRT contains a flood gun, collimator, collector mesh, and storage mesh.

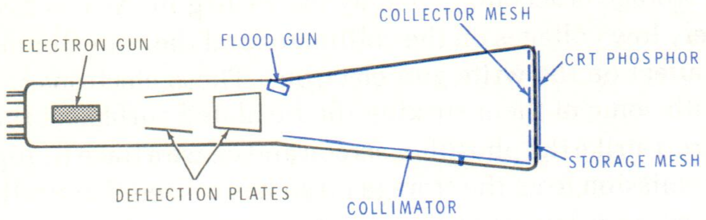


Figure 42

The standard electron gun is called the **write** gun in a storage scope. You will remember that it emits a high velocity stream of electrons which are focused into a very thin beam. In contrast to this, the flood gun emits a low velocity flood of electrons that covers the entire screen. The difference in electron velocity can be better appreciated by remembering that the write gun has a cathode voltage of about −5 kV, while the flood gun has a cathode potential of 0 V.

The collimator is a conductive coating on the inside of the CRT that modifies the path of the electrons from the flood gun so they are parallel to the walls of the tube and each other. Thus, these electrons will strike the screen nearly perpendicular. The collimator potential is approximately 50 V. This voltage will direct the low velocity flood gun electrons but will be too low to affect the high velocity electrons from the write gun.

The collector mesh is a very fine wire screen mounted parallel to the face of the CRT and held at a constant potential that is slightly more positive than the collimator. The correct potential will be around +150 V.

The storage mesh is similar to the collector mesh in construction except that the surface facing the collector mesh is coated with a very thin layer of insulating material. This material is selected to have high secondary emission. That is, when it is struck by high velocity electrons, it gives off electrons and becomes positively charged in that area. This portion of the storage is usually maintained at about −10 V.

The phosphor coating on the CRT is connected to a very high positive potential, usually somewhere between 5 kV and 10 kV.

WRITING

Writing or storage is accomplished by the write gun. As you saw earlier, the relatively low voltages on the collimator and the collector mesh have almost no affect on the write gun electrons. These electrons crash right through with some of them striking the insulated surface of the storage mesh. The rest strike the phosphor screen and cause a trace to appear. The secondary emission from the storage mesh has caused that portion of the mesh to become slightly positive. Once a presentation has been written or stored, the write gun can be turned off and the presentation will remain visible. The electrons emitted by the flood gun are accelerated toward the phosphor coating by the positive potential on the collimator and the collector mesh. These potentials are rather low and the electrons will not have enough energy to pass the −10 V potential on the storage mesh. They can, however, penetrate the areas that have been made positive by secondary emission.

Once an electron penetrates the storage mesh, it will be accelerated by the high positive potential on the phosphor and will have enough energy to cause the phosphor to glow. This charge on the storage mesh will remain for about two minutes. Thus, we see that storage time is limited by the ability of the storage mesh to retain a charge.

Initially, the insulated surface of the storage mesh is charged to −10 V, much as a capacitor is charged. It is the ability to retain this charge that determines storage time. As soon as the tube is placed in the storage mode, that is, the flood gun is turned on, the gas molecules within the tube are ionized by the flood gun electrons. These positive ions are attracted to the negative storage surface, making it less negative.

As the storage surface becomes less negative, it loses its ability to hold back the flood of electrons. Eventually, the entire phosphor screen begins to glow and contrast between the background and the displayed waveform is lost.

Storage time can be increased by turning the flood gun on for a short period and then off again. However, this reduces the brightness of the display. A compromise must therefore be made between storage time and brightness.

ERASING

Often it is desirable to erase the stored presentation before the storage time has elapsed. To accomplish this, storage scopes are provided with an **ERASE** control. The erase control applies collector mesh potential to the storage mesh. The entire storage surface is momentarily charged to a uniform high positive potential after which it is returned to its original voltage of −10 V. The entire erase process requires only a few hundred milliseconds.

VARIABLE PERSISTENCE

Storage scopes are often referred to as variable persistence scopes. Variable persistence means variable storage time. This variable storage time is accomplished by the erase function. In the variable mode, the display is not erased suddenly with a high potential, but slowly with pulses of a lower potential.

Before the display is stored, the potential on the insulated surface of the storage mesh is −10 V. In the area where information is stored by the write gun, the storage potential is near 0 V. Thus, in order to erase the display, the entire storage mesh can be made 0 V. This is accomplished in the variable persistence mode by applying positive pulses of about 10 V to the storage mesh. Each time a pulse is applied, the storage mesh becomes less negative. Therefore, the rate at which the display is erased can be controlled by adjusting the PW and PRT of the pulse. A wide PW and a short PRT will erase the display rapidly, while a narrow PW and a long PRT will allow the display to persist for a relatively long time.

Another term that is used for the variable persistence oscilloscope is "continuous erase scope," because the display is continuously being erased even while it is being displayed.

You have seen that the storage oscilloscope provides a means for displaying very low frequency information. There is also an oscilloscope available for viewing very high frequency signals. It is called a sampling oscilloscope.

Sampling Scopes

The sampling technique extends the frequency range of the oscilloscope far beyond what is possible with a real time scope. Effective bandwidth of up to 18 GHz is possible when using the sampling technique. This is accomplished by converting a high frequency, repetitive signal to a low frequency.

Figure 43 shows how such a conversion is made. The waveform shown in black is the one we wish to measure. The sampling sequence starts at a reference point (R) which is time zero. After one time interval (1T), the incoming signal is sampled and the sample stored in memory. Nothing else is done until the input once more passes the reference. This time, the sampling circuits wait for two time intervals after R to take a sample. The result of this sampling is also stored in memory. The sequence is continued until a predetermined number of time intervals have passed.

When the sampling is complete, all of the samples, in this case, 10, are recalled from memory and plotted on the oscilloscope as shown in Figure 44. Notice that the shape of the waveform is the same as in Figure 43; however, it is expanded in time.

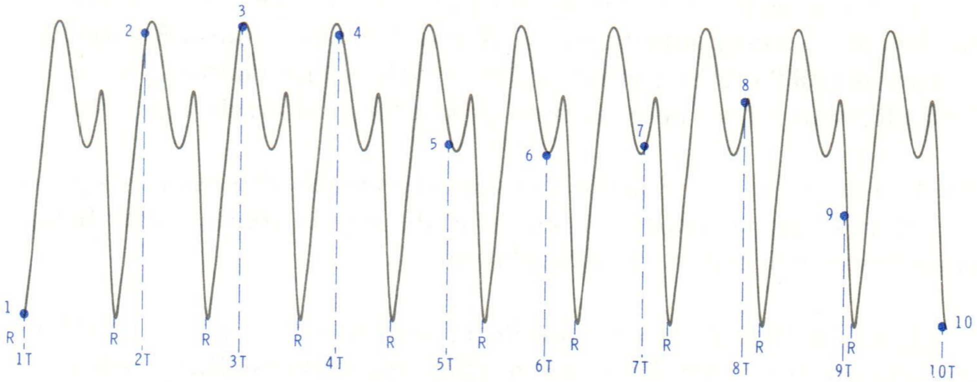


Figure 43

In the example used here, ten samples were taken, one from each of ten waveforms. This gives a 10:1 reduction in frequency and provides a reasonable reproduction of the waveform. However, in actual practice, 100 or more samples would be taken for a greater frequency reduction and much better waveform fidelity.

The major drawback of the sampling oscilloscope is that the input must be repetitive. With that limitation, the sampling can perform any measurement that can be performed with a real time scope. Modern sampling scopes are easy to use, many having only one additional control.

This course will not discuss sampling techniques in detail; however, most manufacturers provide excellent operating manuals which should enable you to use their scopes.

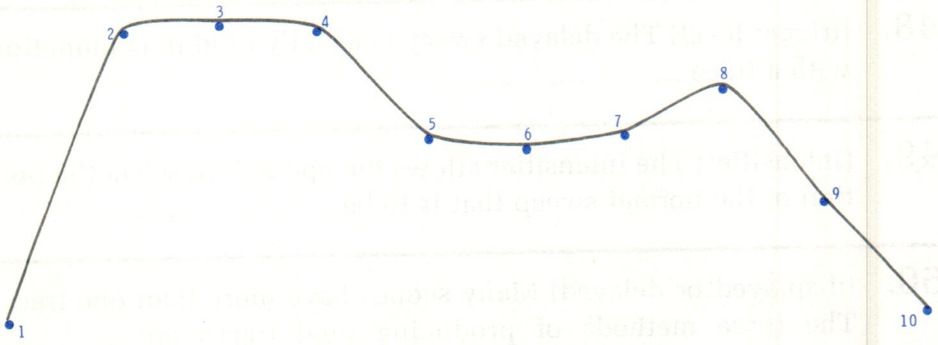


Figure 44

Programmed Review

44. A special feature which allows a portion of the waveform to be enlarged is the sweep ____________.

45. (magnifier) A major drawback of the magnifier is its limited range and the fact that it also magnifies timing _________.

46. (error) Most of these disadvantages can be overcome with a __________ _________.

47. (delayed sweep) The delayed sweep uses a separate time base which starts when the normal sweep passes through a selected _________ ________.

48. (trigger level) The delayed sweep is usually used in conjunction with a trace ______________.

49. (intensifier) The intensifier allows the operator to select the portion of the normal sweep that is to be ______________.

50. (displayed or delayed) Many scopes have more than one trace. The three methods of producing dual traces are _______, _____________ and _______ _______.

51. (chop; alternate; dual beam) The two most common of these are usually incorporated into the same scope; they are _______ and _____________ .

52. (chop; alternate) The _______ method of dual trace presentation cuts the sweep into sections.

53. (chop) This method is normally used at ________ frequencies.

54. (lower) The ________ method shows first one trace then the other.

55. (alternate) This method is usually used at ________ frequencies.

56. (higher) The ________ scope is a special scope that permits viewing of very slow signals.

57. (storage) In addition to the normal scope components, the storage CRT contains a special gun called a ________ gun.

58. (flood) Storage scopes may also be called ________ ________ or ________ ________.

59. (variable persistence; continuous erase) A scope which allows viewing of very high frequencies is the ________ scope.

60. (sampling) A sampling scope takes samples of ________ waveforms and combines these into one ________ ________ signal.

61. (many; lower frequency) A limitation of the sampling scope is that the input signal must be ________.

(repetitive)

CONTROLS

So far, we have discussed oscilloscope circuits. In the rest of this unit, we will discuss the operation of oscilloscopes. In order to properly operate a scope, you must thoroughly understand the function of all the controls. The following explanation is based on the Heathkit Model IO-4541 oscilloscope. It is a relatively simple scope and easy for the beginner to understand. If you are using a different model of scope, you should use your handbook with this lesson.

CRT Controls

Figure 45 shows the front of the IO-4541 oscilloscope with the CRT controls highlighted. A **graticule** is placed on the face of the CRT. This is an 8 × 10 cm grid which allows us to measure the time and amplitude of a signal. With this scope, the graticule is a separate piece of clear plastic mounted in front of the CRT. Since this mounting arrangement places the graticule well in front of the trace on the CRT, the possibility of parallax exists.

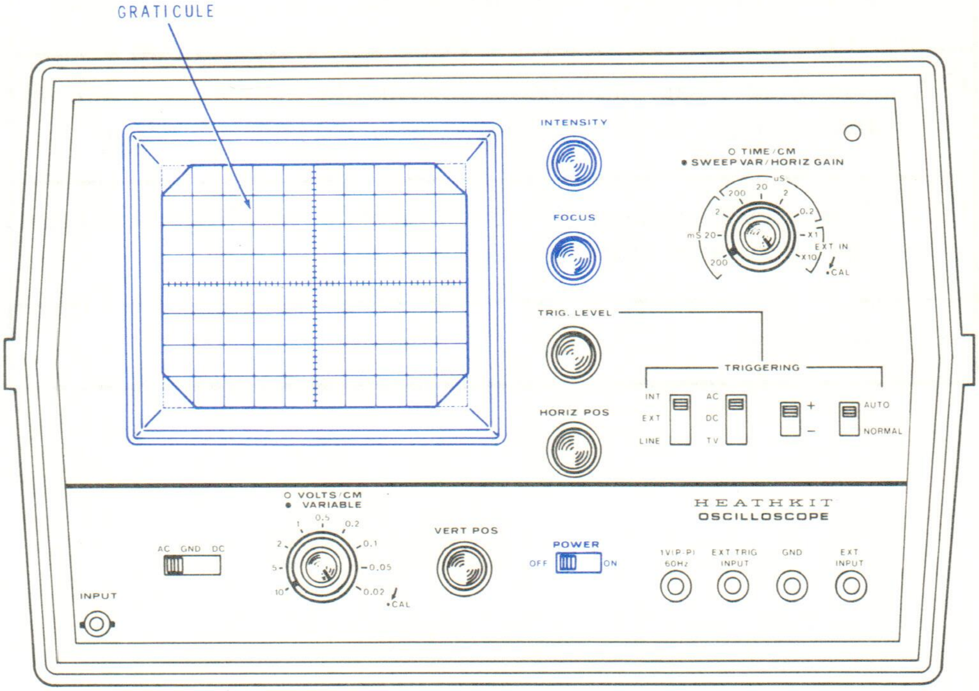


Figure 45

On more expensive scopes, the graticule will be etched on the outside face of the CRT. The graticule is separated from the trace only by the thickness of the CRT face. While possible parallax error is reduced with this arrangement, it is not eliminated. For this reason, the very best scopes have the graticule etched on the inside face of the CRT on the same plane as the phosphor coating. This removes any possibility of parallax error. While the graticule is not actually a control, it is such a necessary part of the scope that meaningful measurement would be very difficult without it.

The control located in the upper center of this scope is the **intensity** control. This control is equivalent to the brightness control on your television and is present on all oscilloscopes. The intensity control varies the intensity or brightness of the trace on the CRT. CAUTION: If the brightness is set too high, there is a danger of burning the phosphor. Once the phosphor has been burned, the damage is permanent. Therefore, the intensity control should only be adjusted for the minimum brightness for comfortable viewing. If a very bright trace is necessary, it should be left at that level only for the time necessary to make the reading, then reduced. Never allow a bright spot to remain in one place on the screen. This is a sure way to burn the phosphor.

The **focus** control adjusts the trace, or the spot on the screen. It, therefore, affects the thickness of the trace. It is usually adjusted for the thinnest trace possible. When high brightness is required, it is sometimes necessary to defocus the trace to prevent burning the phosphor.

The **astigmatism** control changes the shape of the spot on the screen. It is usually adjusted for a round spot. On many scopes, the astigmatism control is not a front panel adjustment. On the Heathkit IO-4541 Oscilloscope, the cover must be removed to make this adjustment. With other scopes, there may be a hole in the case, allowing a screwdriver adjustment.

The **power** switch is included in this section because it is often incorporated into the intensity control. Obviously, it must be on before any other controls are functional.

Sweep and Horizontal Controls

Figure 46 shows the Heathkit IO-4541 Oscilloscope with the sweep controls highlighted. Sweep controls are used to control the start, time, length, and position of the horizontal trace.

The **triggering** controls control the start of the sweep. Since the sweep must start at the same point relative to the input waveform, the trigger source should be a signal which is related in time to the incoming signal. This scope and most other scopes have three trigger sources. They are the incoming signal, the power line voltage, and an external source.

Slide switches, mounted in a row, control the trigger functions of the example scope. In other scopes, the switching arrangement may be different but the functions will be similar. The extreme left-hand switch is the **source** switch, and has three positions:

> The **INT** (Internal) position causes the trigger to be derived from the signal being displayed, and is probably used more than any other source.

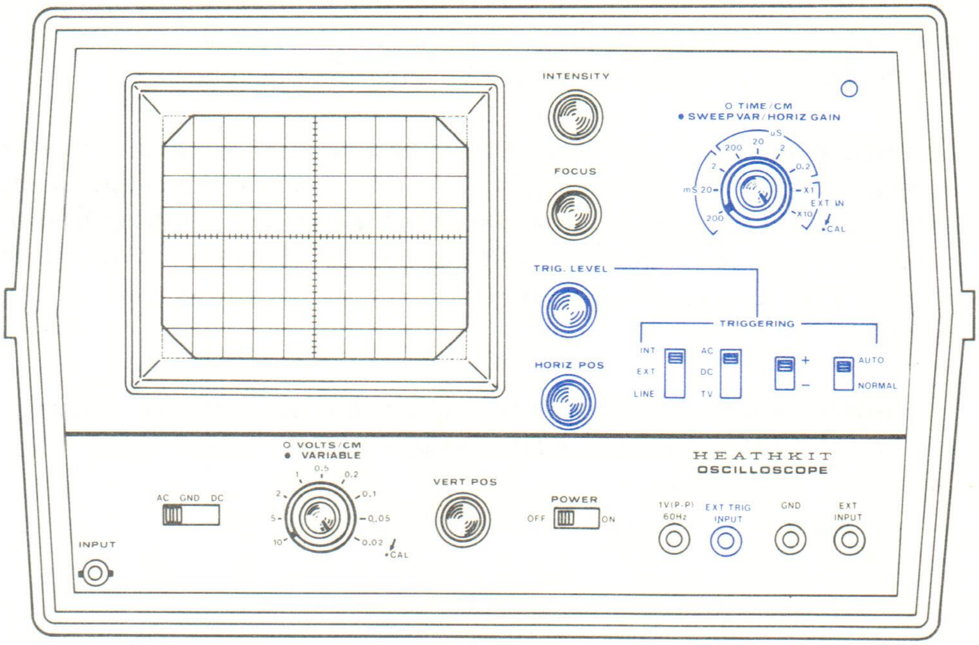


Figure 46

The **EXT** (External) position requires that a signal be fed into the **external trigger input.** This arrangement is used quite often when working with digital circuits.

The **Line** position uses a sample of the power line voltage to trigger the sweep. This position is most useful when working with power supply circuits. Since the ripple frequencies are a multiple of the line frequency, the timing will be correct for a readable display. The sample from which the trigger is derived is constant in amplitude and not dependent on the incoming signal. Therefore, the trigger level does not need to be readjusted for different amplitude signals.

The selected trigger source must be coupled to the trigger circuits. There are typically two types of **trigger coupling;** AC and DC. In the **AC** position, the trigger signal is coupled through a capacitor to the trigger circuits. The capacitor blocks the DC portion of the signal and passes the AC portion.

The **DC** position allows the sweep to trigger on very slow changes in voltages. In this position, the signal upon which we wish to trigger is coupled directly to the trigger circuits.

In addition to the two types of triggering just mentioned, the Heathkit IO-4541 Oscilloscope has a position labeled **TV**. In the TV position, the signal is coupled through C_1 (Figure 47) to a low-pass filter composed of R_1 and C_2. This removes the video from the incoming TV signal. D_1 insures that the output is a positive pulse with a reference of 0 V. This circuit allows the triggering circuits to be synchronized to the vertical frame rate of a video TV signal.

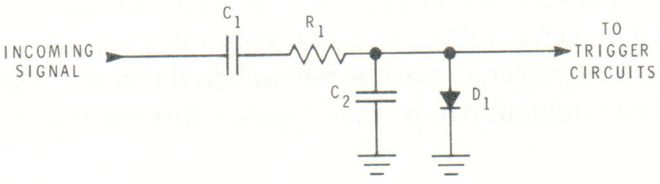


Figure 47

The next switch is the **SLOPE** selector. The sweep may be triggered on the positive-going (+) or the negative-going (−) part of the signal.

The **TRIG. LEVEL** sets the amplitude on the waveform where the trigger occurs. This control, along with the **SLOPE** selector, lets us look at any portion of the waveform we wish.

The **AUTO/NORMAL** or mode switch is next. The difference between these two positions only becomes apparent when the displayed signal is lower in amplitude than the selected trigger level. In the **NORMAL** position, when the incoming signal is too small or the **TRIG. LEVEL** is not set right, there will be no trace on the screen. However, if the switch is placed in the **AUTO** position, an automatic baseline or trace will be generated. Of course, any incoming signal will be superimposed on this trace. The presentation will most likely not be properly synchronized. If the trigger level is adjusted so that the trigger voltage is greater than the trigger level, the display will synchronize. This mode is very useful for locating a waveform when you are unsure of the amplitude.

The final sweep control is actually two controls in one. The outer ring is labeled **TIME/CM** and controls the time it takes the sweep to transverse one centimeter on the screen. As shown in Figure 46, the control is in the 200 mS/CM position. In this position, it will take the trace 200 mS to cover 1 centimeter. Since the screen is 10 centimeters wide, it takes the beam two seconds to complete one sweep. Speeds of 200 mS/CM up to 0.2 μS/CM are available with this scope. The ×1 and ×10 positions have a different purpose and will be discussed later.

The **TIME/CM** which is selected by the outer ring is only accurate if the inner control, the **SWEEP VAR/HORIZ GAIN** control, is turned all the way clockwise to the **CAL** position.

When used as a sweep control, this knob varies the sweep time. It is useful for viewing a waveform, the period of which is not equal to one of the times selected. However, it must be remembered that no accurate time or frequency measurement can be made unless this control is in the **CAL** position.

The entire display can be moved left and right by means of the **HORIZ POS** control. This allows any part of the waveform to be aligned with a point on the graticule; thus, allowing more accurate measurement of time and frequency.

It is also possible to feed external information into the horizontal channel. To accomplish this, the **TIME/CM** control must be turned to one of the **EXT IN** (external in) positions. There are two positions, ×1 and ×10. In the ×10 position, the input is attenuated by a factor of 10.

When in the **EXT IN** position, the **SWEEP VAR/HORIZ GAIN** control is used to control the gain in the horizontal channel. The **HORIZ POS** control works as before and is used to position the presentation left and right on the screen. In this mode of operation, the input to the horizontal channel is connected to the **EXT INPUT** jack in the lower right corner of the scope. The **GND** is a ground connection for the horizontal channel.

Vertical Controls

The remainder of the controls apply to the vertical channel. Vertical signals are fed into the scope through the coaxial connector in the lower left corner labeled **INPUT**. The signal is then coupled to the vertical amplifier. The **INPUT COUPLING** switch selects the method of coupling.

The switch has three positions, **AC, GND**, and **DC**. In the **GND** position, chassis ground is placed on the vertical input. This establishes a zero-volt reference from which DC voltages can be measured. The **AC** position of the switch couples the incoming signal through a capacitor which blocks any DC component and allows the AC to pass. This position is most useful for measuring AC which is superimposed on a relatively large DC. In the **DC** position, all components of the incoming signal are coupled directly to the vertical amplifier. In this position, both AC and DC measurements can be made.

The **VOLTS/CM** control sets the vertical sensitivity in volts-per-centimeter when the **VARIABLE** control is in the **CAL** position. Thus, it is possible to obtain the value of either AC or DC voltages. We will discuss later exactly how a measurement is made.

When the **VARIABLE** control is moved from the **CAL** position, the volts-per-centimeter reading is no longer accurate. The **VARIABLE** control is usually used to compare the input with a known value.

The **VERT POS** control is used to position the presentation in an up and down direction.

A **1 V (P-P 60 Hz)** jack is provided on the front of the scope to aid in calibration. On this particular scope, a 60 Hz sine wave with a peak-to-peak amplitude of 1 V is furnished. More expensive scopes will provide a square wave with a frequency of about 1 kHz and a specified amplitude. The 1 V amplitude is common. The square wave allows probe calibration as well as amplitude calibration. However, the probe can be calibrated from any square wave source.

Probes

While the oscilloscope probe isn't actually one of the scope controls, its selection and use is so crucial to accurate measurement that we have included it in this section.

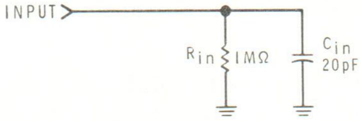


Figure 48

Before starting the discussion of probes, let's look at the characteristics of the oscilloscope input. In the typical scope, the input is a high resistance shunted by a low value of capacitance as shown in Figure 48. When the oscilloscope is connected to the circuit under test, the scope input modifies that circuit and may, depending upon the circuit, cause changes in circuit operation. In any case, the scope loads down the circuit so that the voltage being measured is less than the unmodified circuit voltage. This loading effect depends on the ratio of scope input resistance (R_{in}) to signal source resistance (R_g). You can calculate it with the formula:

$$\text{Percent error} = \frac{R_g}{R_g + R_{in}} \times 100$$

You can see by this that an R_{in} equal to 10 times R_g will have a loading error of less than 10%. For a loading error less than 1%, an R_{in} of at least 100 times R_g is required.

All of this is fairly simple, but it only applies as long as the input capacitance (C_{in}) is not a factor. However, C_{in} is almost always a factor. Therefore, to determine loading effect, we must consider the input impedance (Z_{in}) not just the resistance. Since R_{in} and C_{in} are in parallel, you can calculate the impedance by,

$$Z_{in} = \frac{R_{in} \times X_{cin}}{\sqrt{R_{in}^2 + X_{cin}^2}}$$

where

$$X_{cin} = \frac{1}{2\pi f C_{in}}$$

This should bring us to the conclusion that Z_{in} changes with frequency, becoming less as frequency increases. To understand the magnitude of this change, compare the X_c of a typical 20 pF C_{in} at the following frequencies.

f	X_c
500 Hz	16 MΩ
1 kHz	8 MΩ
10 kHz	800 kΩ
100 kHz	80 kΩ
1 MHz	8 kΩ
10 MHz	800 Ω
100 MHz	80 Ω

Since Z_{in} can never be greater than the smaller of R_{in} and X_{cin}, but can be considerably less than either, the frequency doesn't get very high before the effect of C_{in} becomes evident. As a matter of fact, it is often of more importance than resistance loading.

It should now be apparent that the percentage of error is a factor of Z not of R. Therefore, you can find the percentage of error by:

$$\%\text{ error of} = \frac{Z_{in}}{Z_{in} + Z_g}$$

where Z_{in} is the scope input impedance and Z_g is the impedance of the signal source.

Up till now, we haven't even connected the scope to the circuit under test. Obviously, to do so requires the use of some sort of cable or test leads. A simple test lead is subject to a large amount of external interference, such as, 60 Hz line frequency or stray RF fields. This noise often makes it impossible to measure small signals. To prevent this interference, some form of coaxial cable is usually used as a connection. However, this too, has its drawbacks.

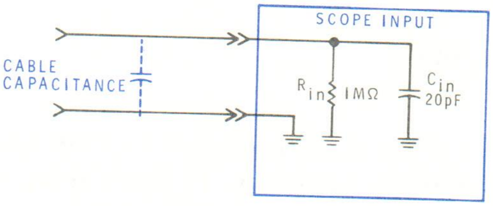


Figure 49

For example, one of the most common coaxial cables, RG-58/U, has 25.8 pF of capacitance per foot. This capacitance is connected in parallel with the input capacitance of the scope as shown in Figure 49. Thus, if a 3 ft. length of cable is used, the cable capacitance will be 85.5 pF. This is added to the scope capacitance making the total capacitance connected to the circuit 105.5 pF.

At 1 MHz, this capacitance has a reactance of only 1509 Ω. If we calculate Z_{in} using the formula discussed earlier, we find it to be only 1508 Ω. Thus, we can see that X_{cin} is so low that R_{in} can be ignored. If this scope lead combination is connected to an R_g of 1 kΩ, the voltage measured will be only 60% of the actual voltage.

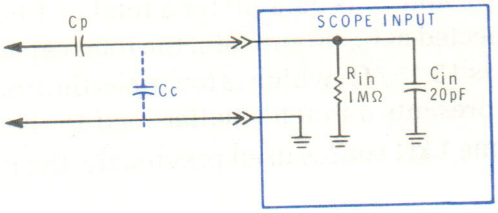


Figure 50

If the frequency increases to 10 MHz, X_c drops to a mere 151 Ω and the measured voltage drops to 13% of the actual value. Obviously, with this amount of error, a meaningful measurement is impossible.

Since the capacitance of the cable and the scope input cannot be eliminated, it must be compensated for. To do this, a capacitor is placed in series with the input, as shown in Figure 50.

We know that when capacitors are connected in series:

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots \frac{1}{C_n}}$$

Therefore, the total capacitance will always be less than the smallest capacitor. We can, thus, adjust the value of probe plus scope capacitance by controlling the value of C_p. If C_p is one ninth the value of C_c and C_{in} combined, the result will be a 10:1 capacitive voltage divider.

For example, using the same scope and cable combination we discussed earlier, C_{in} is 20 pF and C_c is 85.5 pF for a total of 105.5 pF. If an 11.7 pF capacitor is connected at C_p (Figure 50), the total capacitance will be 10.5 pF. At 1 MHz, X_c is 15,157 Ω, which is ten times the previous X_c of 1508 Ω. This, of course, presents a much smaller load to the circuit under test. Assuming the same 1 kΩ source used previously, the percentage of signal loss is:

$$\% \text{ Loss} = \frac{Z_{in}}{Z_{in} + Z_g} \times 100$$

$$= \frac{15157}{15157 + 1000} \times 100$$

$$= 93.8\%$$

which means that only about 6% of the source signal is lost due to loading.

All of this signal, however, is not applied to the scope input. There is a 10:1 division between C_p and $C_{in} + C_c$, allowing only 10% of the available signal to be applied to the scope input. Therefore, the VOLTS/DIV setting must be multiplied times ten to get the actual volts/division.

While the load on the circuit under test changes with frequency, the capacitive voltage divider ratio remains constant. The actual voltage division, however, does not remain constant due to the effect of R_{in}. As the input frequency decreases, the reactance increases until, at some frequency below 1 MHz, R_{in} becomes the determining factor for Z_{in}. Therefore, while X_{cp} continues to increase, Z_{in} will tend to remain constant, and the voltage division ratio will change.

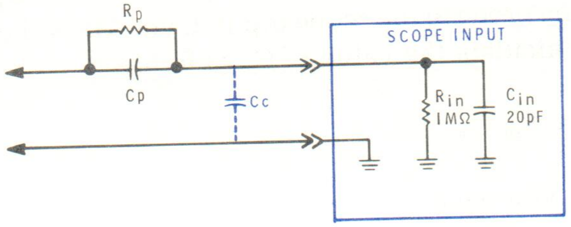


Figure 51

To overcome this tendency, a resistor is added in parallel with C_p, as shown in Figure 51. If this resistor (R_p) is made 9 times the value of R_{in}, the voltage ratio will remain essentially constant at all frequencies. For instance, if R_p is 9 MΩ, the voltage ratio is 10:1 for DC and remains 10:1 as frequency increases. In this manner, we have effectively increased the input impedence of the scope by a factor of 10 and reduced the loading on the circuit under test.

The constant division ratio is only present if the probe is properly compensated. For the probe to be properly compensated, the RC time of the probe must equal the RC time of the scope input, which includes any cable capacitance. For instance, in the scope and probe just discussed, $R_P = 9$ MΩ and $C_p = 11.7$ pF for an RC time of 10.5 mS. The scope has an R_{in} of 1 MΩ and a $C_{in} + C_c = 105.5$ pF for an RC time of 10.55 mS. Thus, the RC time of the probe equals the RC time of the scope, and the probe is properly compensated.

Most probes are designed for use on a variety of scopes. Since C_{in} may vary from scope to scope, C_p is usually a variable capacitor to allow matching of the probe to the scope input. If you know the value of R_{in} and C_{in}, you can calculate the value of C_p as follows:

$$R_p C_p = R_{in} C_{in}$$

solving for C_p you have:

$$C_p = \frac{R_{in} C_{in}}{R_p}$$

If R_{in} is 1 MΩ and C_{in} is 47 pF, let's see what C_p and R_p will be. For a 10:1 probe, $R_p = 9 R_{in}$, in this case 9 MΩ.

$$C_p = \frac{1\ \text{M}\Omega \times 47\ \text{pF}}{9\ \text{M}\Omega}$$

$$= 5.2\ \text{pF}$$

Actually, the value of C_p is seldom calculated. Instead, you usually would make the adjustment by observing a square wave and adjusting for the best shape, as shown in Figure 52. Figure 52A shows a square wave with the high frequencies attenuated too much. Figure 52B is the correct waveform with all frequencies handled the same, while Figure 52B does not attenuate the high frequencies enough. Thus, when C_p is adjusted until the display looks like Figure 52B, with a square wave input, the probe is properly compensated. The calibration control can be a screwdriver adjustment, a knurled ring, or some other arrangement.

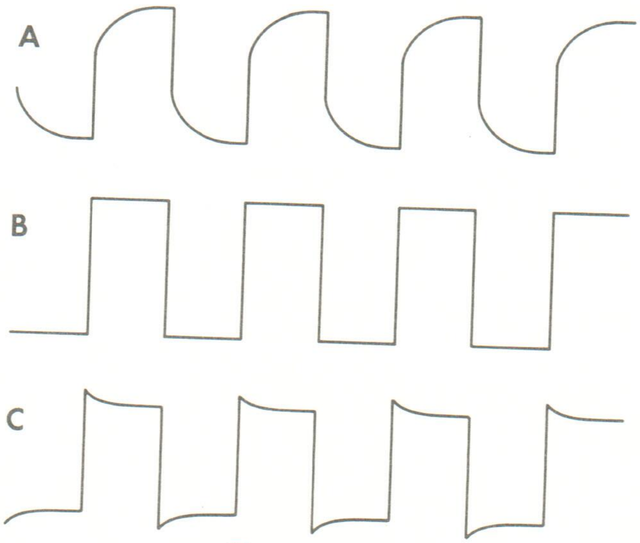


Figure 52

Programmed Review

62. The ______________ of an oscilloscope is an etched grid that allows the measurement of amplitude and time.

63. (graticule) The intensity control varies the ________________ of the trace on the CRT.

64. (intensity) The __________ control adjusts the thickness of the trace.

65. (focus) The control that controls the start of the trace relative to the input waveform is the _________________ control.

66. (triggering) The trigger source switch usually has three positions. They are _____________, ______________ and ________.

67. (internal, external; line) Most scopes also have ____ and ____ trigger coupling.

68. (AC; DC) By adjusting the __________ selector and the ___________ ________ we can view any portion of a waveform.

69. (slope; trigger level) When the mode switch is in the ___________ position, no trace will appear on the CRT unless a trigger is present.

70. (normal) However, an automatic base line trace is generated in the ________ position.

71. (auto) The ________/______________ control controls the time it takes the sweep to transverse one division on the CRT.

72. (time/division) For this control to be accurate, the sweep var/horiz gain control must be in the ________ position.

73. (CAL) The ____________________ switch selects the method by which the input signal is coupled to the scope.

74. (input coupling) On most scopes, this control has three positions, ________ ________ and ______________ .

75. (AC; DC; GROUND) The vertical sensitivity is set by the __________/__________ control.

76. (VOLTS/CM) This control is only accurate if the variable control is in the ________ position.

77. (CAL) When using a ×10 probe, the input signal is __________________ by a factor of ________ .

(attenuated; 10)

Experiment 5

OSCILLOSCOPE CONTROL OPERATION

OBJECTIVE: *To demonstrate the operation and function of the various oscilloscope controls.*

Material Required

Oscilloscope, Heathkit Model IO-4541 or equivalent,

Heath PKW-101 ×10 Probe or equivalent,

Heathkit Electronic Design Experimenter, Model ET-3100

Introduction

Before applying power to the oscilloscope, you should make certain preliminary settings. The location of the controls for the Heathkit IO-4541 Oscilloscope is shown in Figure 53. Since the names are fairly common, you should have no trouble converting these instructions to any model oscilloscope.

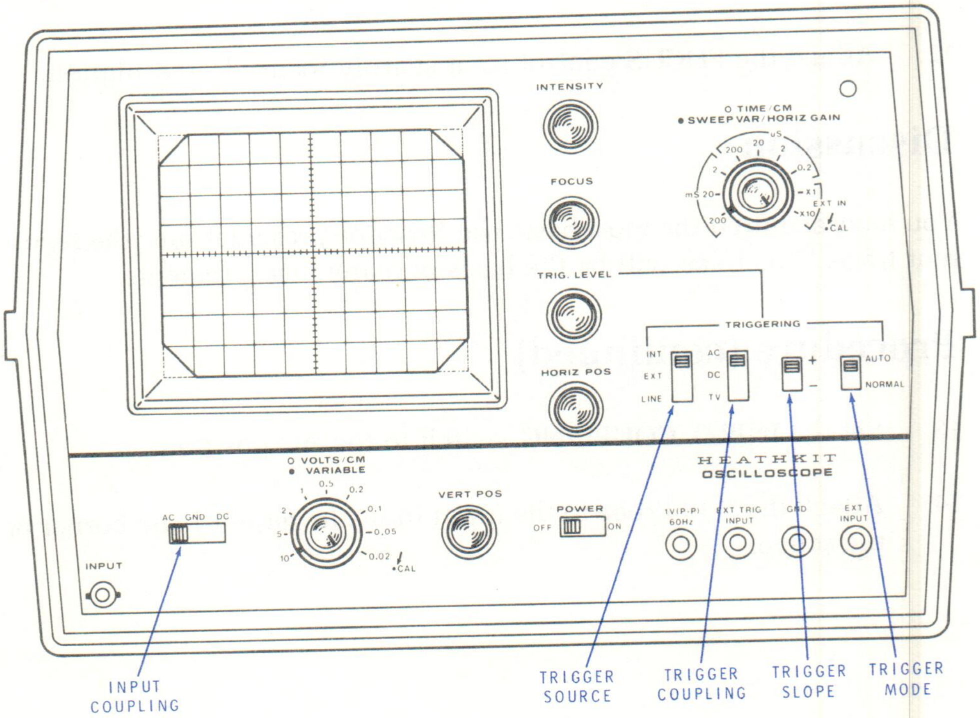


Figure 53

Procedure

1. Turn the **INTENSITY** control to midrange.
2. Set the **TRIGGER SOURCE** switch to the **INT** position.
3. Set the **TRIGGER MODE** switch to the **AUTO** position.
4. Set the **TIME/CM** control to the **2 μS** position and the **SWEEP/VAR** to **CAL**.
5. Set the **HORIZ POS** control to midrange.
6. Set the **INPUT COUPLING** switch to the **GND** position.
7. Set the **VOLTS/CM** control to 10 and the **VARIABLE** to **CAL**.
8. Set the **VERT POS** control to midrange.
9. Connect the oscilloscope to the proper power source.
10. Turn the **POWER** switch **ON**.
11. Allow the oscilloscope to warm up for one minute, then adjust the **VERT POS** and **HORIZ POS** controls to center the sweep on the scope.
12. Adjust the **FOCUS** control for a sharply focused presentation.

Discussion

You have acquired the most basic oscilloscope presentations, the recurrent trace. This trace will be the basis of many measurements.

Procedure (continued)

13. Set the **INPUT COUPLING** switch to the AC position.
14. Attach the ×10 Probe to the Input in the lower left-hand corner of the scope.

WARNING: In the following step, be sure that the ground clip is NOT connected to pin 1 or pin 3. This will directly ground the output of the power transformer and will blow the power fuse inside the Experimenter.

15. On the Electronic Design Experimenter, connect the ×10 Probe to either Pin 1 or Pin 3 of the line frequency output in the upper center of the trainer. Connect the ground clip from the probe to the center tap ground, pin 2 of the line frequency transformer.

16. Set the **TIME/CM** control to the 2 mS-per-centimeter position. Any setting of this control which gives from one to three complete wave forms on the scope will be adequate for this experiment.

17. Set the **VOLTS/CM** control to a position that allows the entire waveform to be displayed on the oscilloscope. A total deflection of from four to six centimeters is desirable for most amplitude measurements.

18. Make sure that both the **SWEEP/VAR** and the **VARIABLE** control are in the calibrate position.

19. Set the trigger slope control to the plus (+) position and the trigger mode control to the **NORMAL** position. Then adjust the **TRIG LEVEL** control for a stable display on the screen. You should now have a presentation similar to that shown in Figure 54.

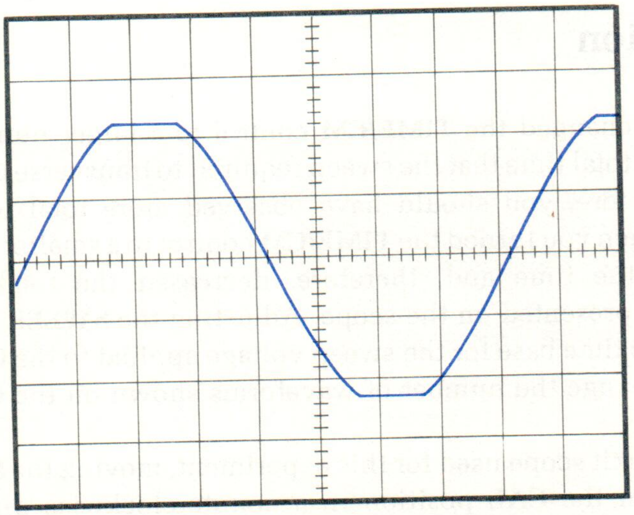


Figure 54

Discussion

The waveform shown here is a sample of the 60 Hz line frequency signal applied to the power supply of the Electronic Design Experimenter. The clipping on the peaks of the waveform is due to saturation of the transformer core during current peaks. This will have no major effect on the experiment.

Procedure (continued)

20. Increase the **TIME/CM** control setting to the next higher number. What effect does this have on the number of waveforms presented on the oscilloscope? ______________________________
____.

21. Decrease the **TIME/CM** control setting to the next smaller number. What effect does this have on the number of complete cycles on the CRT? ______________________________
____.

    Return the **TIME/CM** control to a setting that gives between one and three complete waveforms on the face of the CRT.

22. Turn the **SWEEP VAR** control from the **CAL** position slowly counterclockwise, and observe its effect on the number of waveforms presented on the CRT. What is this effect? ______________
____
____

Discussion

When you changed the **TIME/CM** control to a larger number, you increased the total time that the sweep required to transverse the face of the CRT. Therefore, you should have observed more total waveforms of voltage. When you turned the **TIME/CM** control to a smaller number, you decreased the time and, therefore, decreased the total number of waveforms presented on the scope. Adjusting the **SWEEP VAR** control changes the time base for the sweep voltage applied to the CRT. Thus, it will also change the number of waveforms shown on the CRT.

In the Heathkit scope used for this experiment, moving the **SWEEP VAR** control from the **CAL** position in a counterclockwise direction, will increase the time-per-centimeter and will increase the number of waveforms presented on the scope. Other scopes may work in the opposite direction.

Procedure (continued)

23. Slowly adjust the **TRIG LEVEL** control both clockwise and counterclockwise. What effect does this adjustment have on the presentation on the CRT? ______________________________

____.

24. Change the **TRIGGER SLOPE** control from plus to minus. What effect does this have on the presentation on the CRT? __________

____.

25. Adjust the **HORIZ POS** control clockwise and counterclockwise. What effect does this have on the presentation on the CRT? ______

____.

26. Adjust the **FOCUS** control both clockwise and counterclockwise. What effect does this have on the presentation on the CRT? ______________________ . Return the **FOCUS** control to the sharpest trace.

27. Adjust the **INTENSITY** control clockwise and counterclockwise and note the effect that this has on the presentation on the CRT. __________________ . Return the **INTENSITY** control to a comfortable viewing level.

28. Change the **NORMAL/AUTO** switch to the **AUTO** position. Note the effect that this has on the presentation on the CRT, and return the control to the normal position. ____________________. Change the **AC, DC, TV** control to **DC** and note the effect on the presentation, then to **TV** and note the effect on the presentation. ______________________ Return the control to the **AC** position. Change the **TRIGGER SOURCE** switch to the **LINE** position and note the effect on the presentation on the scope. ____________________ . Change the **TRIGGER SOURCE** switch to the **EXT** position and note the effect on the presentation on the scope. ________________________. Why does this occur? ________________________. Return the **TRIGGER SOURCE** switch to the **INT** position.

At this point, make sure that the triggering switches are in the following positions: **TRIGGER SOURCE**, internal. **TRIGGER COUPLING**, AC. **TRIGGER SLOPE**, positive: and **TRIGGER MODE**, normal. Also, make sure that the **SWEEP VAR** control is in the **CAL** position.

29. Adjust the **TRIG LEVEL** control until the beginning of the positive-going portion of the trace starts well below the center horizontal line across the screen.

30. Adjust the **HORIZ POS** control until the positive-going portion of the trace crosses the center horizontal line at one of the major vertical lines. The presentation you now have should be similar to that shown in Figure 55.

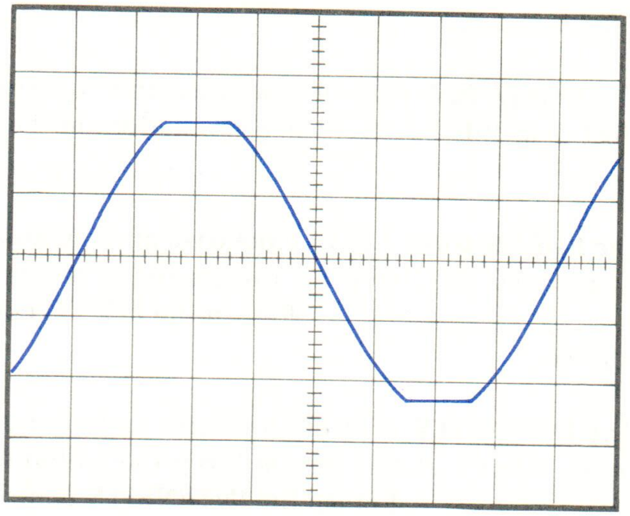


Figure 55

31. Count and record the number of centimeters required for one cycle on the face of the CRT. 6 .

32. Multiply the number of centimeters times the **TIME/CM** setting. This will give the total time for one complete waveform. Record this number. 12 . Since $f = \frac{1}{t}$, the frequency of the waveform can be found by using this formula. Calculate and record the frequency. ________ .

Discussion

If you were using the Heathkit Model IO-4541 Oscilloscope, the total number of divisions should have been approximately 8.1. The **TIME/CM** control would have been set at 2 mS per centimeter. Two times 8.1 would give approximately 16.2 mS for the total period of the waveform. Taking the reciprocal of this will give approximately 60 Hz, which is the frequency of the input waveform.

Procedure (continued)

33. Make sure that the **VARIABLE** voltage control is in the CAL position. Then adjust the **VERT POS** control until the bottom of the presentation lines up with one of the horizontal lines.

34. Adjust the **HORIZ POS** control until one of the positive peaks of the presentation lines up with the center vertical line on the scope. The presentations should now appear similar to that in Figure 56.

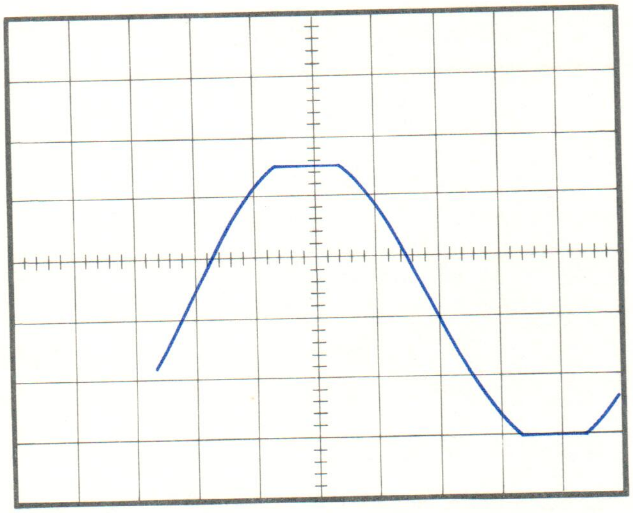


Figure 56

35. Measure the amount of vertical deflection in centimeters and record this number. ______________ To find the peak-to-peak voltage of the waveform, multiply the number of centimeters times the **VOLTS/CM** setting times the probe attenuation.

Discussion

If you are using the Heathkit Model IO-4541 Oscilloscope with a ×10 probe, as specified, the Volts/CM setting should be in the 1 V/CM position. The total peak-to-peak deflection in centimeters should be approximately 4.7 cm. 4.7 times 1 times 10 is equal to 47 volts, peak-to-peak. To convert from peak-to-peak to RMS voltage, divide the peak-to-peak voltage by 2.828. When worked out for the voltage given here, we have an RMS voltage of slightly more than 16 volts. This is well within tolerance for the equipment in use. Remember that this is a direct sample of the power line voltage. Power line voltage can vary from slightly over 90 V to almost 140 V RMS, depending on the time of day and the load placed on the various circuits. Therefore, your voltage may vary considerably from what we have and may, in fact, vary depending on the time of day you make the measurement.

OSCILLOSCOPE MEASUREMENTS

The oscilloscope has often been called the most versatile measuring instrument in the shop or laboratory. Whether this statement is true or not will not be discussed here. However, it is true that the oscilloscope is capable of providing a variety of information. In spite of this claim of versatility, the oscilloscope is capable of measuring only two quantities — voltage and time. In this section, you will see how the two quantities can be used to represent a number of parameters.

Voltage

There are both advantages and disadvantages to measuring voltage with an oscilloscope. The advantages are that shape, phase, and frequency can be viewed while the measurement is being made. Poor resolution is probably the greatest disadvantage, especially at higher voltage levels.

All voltage measurements, and time measurements too, are made with the graticule. The graticule as you learned earlier is a grid, usually 8 × 10 cm superimposed on the face of the CRT. Figure 57 shows how a graticule might appear. Notice that on the center horizontal line (A) and the center vertical line (B), each major division is subdivided into five smaller divisions. Each vertical division has a certain value, depending on the setting of the **VOLTS/CM** control. For instance, if the **VOLTS/CM** is set at 5, then each major division has a value of 5 V, and each subdivision has a value of 1 V. Thus, the resolution is only about ±0.5 V. Depending on the amplitude of the input, resolution varies between 2% and 10%.

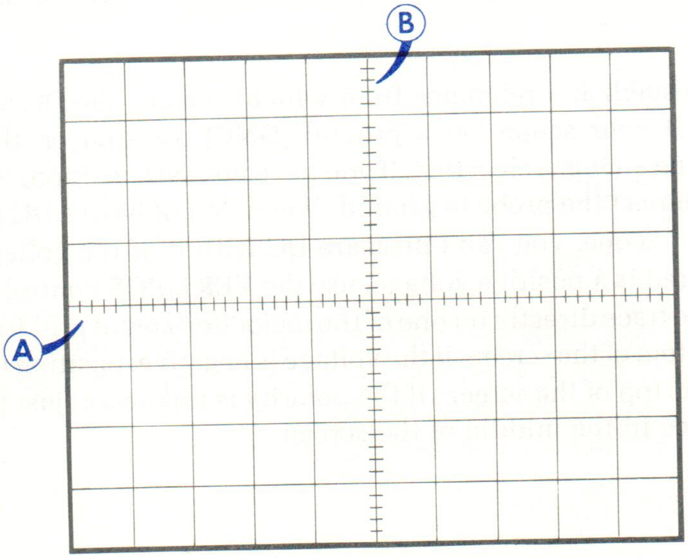


Figure 57

Voltage is measured by counting the number of divisions subtended by the incoming signal and multiplying that by the **VOLTS/CM** setting. For instance, if the display covers four major divisions plus three subdivisions and the **VOLTS/CM** control is set at 2, the voltage at the input is $4.6 \times 2 = 9.2$ V. To determine the actual voltage being measured, this voltage must be multiplied by the probe attenuation. If a ×10 probe were being used, the voltage being measured would be 92 V.

IF the scope being used has DC input coupling available, it is possible to measure DC voltage as well as peak-to-peak voltage and instantaneous voltage.

DC VOLTAGE

As we said, it is possible to measure DC on an oscilloscope if the scope has DC input coupling. Most of the steps in setting up a scope to measure DC are similar to those for measuring any quantity; however, there are differences. Use the following procedure to measure a DC voltage.

1. Turn on the oscilloscope and set up a recurrent trace.

2. Select a deflection sensitivity (Volts/CM) that will give approximately five full divisions of deflection. If you don't know the approximate value of voltage being measured, do as you would with a meter and select the highest value of volts-per-division. This is not to protect the scope. It just keeps the trace on the screen so you can find it. Of course, it is possible to damage the scope with excessive voltage, but this has nothing to do with the sensitivity setting. Make sure that the **VARIABLE** control is in the **CAL** position.

3. Next, establish a reference from which to make the DC measurement. If your scope has a ground **(GND)** position on the input coupling switch, select that. If you have no **GND** position, select **DC** and connect the probe to ground. If you do not have a **DC** position on your scope, you can't measure DC with it. If the voltage to be measured is a positive voltage, use the **VERT/POS** control to position the trace directly on one of the major horizontal grid lines near the bottom of the screen. If the voltage is negative, position the trace near the top of the screen. If the polarity is unknown, just position the trace in the middle of the screen.

4. Using the proper probe, connect the voltage to be measured to the vertical input. If you don't know what probe to use, use a ×10. This will protect the scope from excessive input voltage. If you have the input coupling switch in the **GND** position, now is a good time to move it to the **DC** position.

5. Adjust the **VOLTS/CM** control until the trace moves several divisions from the reference trace. If necessary, change from a ×10 probe to a ×1 probe. A positive voltage will cause deflection toward the top of the screen, and a negative voltage will cause deflection toward the bottom of the screen.

6. Now, interpret the display by counting the number of major and minor divisions subtended by the input. Before going further, it is necessary to convert the number of minor divisions into tenths of major divisions. On Heath scopes and most others, this is easy, as each major division is divided into five minor divisions. Therefore, each minor division will equal 0.2 of a major division.

The unknown voltage can now be determined by multiplying the number of divisions of deflection times the **VOLTS/CM** times the probe attenuation. For instance, if the total deflection is 4.4 cm, the **VOLTS/CM** is set at 0.5, and a ×10 probe is being used, the voltage being measured (V_{in}) can be determined by:

$$V_{in} = 4.4 \times 0.5 \times 10 = 22 \text{ V}$$

Thus, it is quite possible to measure DC voltage with most oscilloscopes. A good meter will do a better job, but the scope can do it.

PEAK-TO-PEAK VOLTAGE

One of the simplest of all voltage measurements to make with the oscilloscope is the peak-to-peak amplitude of an AC voltage. The basic steps required are similar to those for making any type of measurement on an oscilloscope. They are as follows:

1. Turn on the oscilloscope and obtain a free-running trace.

2. Using the proper probe, connect the signal in question to the vertical input. It is usually best to use a ×10 probe unless the signal amplitude is very small.

3. Select the **VOLTS/CM** setting that gives a deflection of about 4 to 6 cm on the screen. Be sure that the **VARIABLE** control is in the **CAL** position. There is nothing magic about the height of the display. Anything that stays on the screen will do.

4. Choose the proper trigger source, coupling, slope, and mode. That usually means **INT**, **AC**, "+", and **AUTO**, respectively. On some older scopes, **AUTO** means a free-running trace that you can't trigger. In this case, use the **NORMAL** mode.

5. Adjust the trigger level for a stable display. You'll find out here which mode you should be in. If you can't get a stable display in **AUTO**, switch to **NORMAL**.

6. Set the **TIME/CM** and the **SWEEP/VAR** controls for a proper display. Unless you are measuring time or frequency, there is no need to have the **SWEEP/VAR** in the **CAL** position. The important thing is that one or more complete waveforms appear on the scope.

7. Using the **VERT POS** control, position the presentation so the bottom of the waveform rests on one of the major horizontal lines. Next, use the **HORIZ POS** control to position one of the peaks exactly on the center vertical line. Figure 58 shows how the presentation might appear.

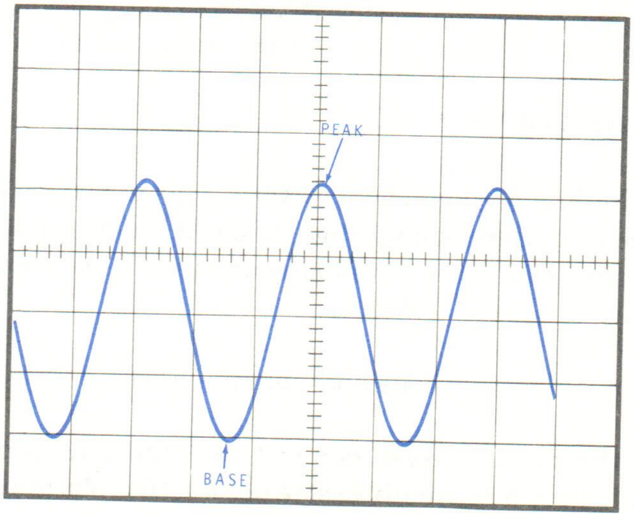


Figure 58

8. Last, interpret the measurement. In Figure 58, if we assume a ×10 probe and a **VOLTS/CM** setting of 0.2, the voltage being measured is $4.4 \times 0.2 \times 10 = 8.8$ V P-P.

If the waveform being measured is a sine wave, the RMS or average value can be calculated by the following formula:

$$\text{RMS} = 0.354 \text{ peak-to-peak}$$

and

$$\text{Average} = 0.318 \text{ peak-to-peak}$$

If the waveform is a square wave, the RMS and average values are the same. The average value may be found by multiplying the peak value times the duty cycle. Duty cycle (DC) is a ratio of pulse width (PW) to pulse-repetition-time (PRT).

Figure 59 shows how a typical square wave might look. Assume that the peak voltage is 10 V, the PW is 10 μS and the PRT is 30 μS. In other words, the voltage is present for 10 μS and absent for 20 μS. The duty cycle is equal to:

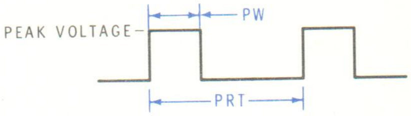


Figure 59

$$\begin{aligned} \text{DC} &= \text{PW/PRT} \\ &= 10/30 \\ &= 0.333 \end{aligned}$$

The average or RMS value may then be found by:

$$\begin{aligned} \text{Average} &= \text{PP} \times \text{DC} \\ &= 10 \times 0.333 \\ &= 3.33 \text{ V} \end{aligned}$$

If the waveform is other than a sine wave or a square wave, it is very difficult to find the average or RMS value. It is seldom necessary, and most troubleshooting charts show a pictorial of the waveform with peak values given.

INSTANTANEOUS VOLTAGE

The instantaneous value is the level of voltage at any given instant of time. We could also say that it is the value of any given point on a waveform. To measure instantaneous voltage, your scope must be capable of measuring DC voltage.

The first five steps in this measurement are the same as for DC voltage, so they will not be covered in detail here.

1. Set up a recurrent trace.
2. Select the proper deflection sensitivity.
3. Establish a reference.
4. Connect the signal to the input.
5. Adjust the **VOLT/CM** control for proper amplitude.
6. Set the triggering controls for a stable display.
7. Adjust the **TIME/CM** and **SWEEP/VAR** controls for the proper display. Figure 60 shows how such a display might appear.

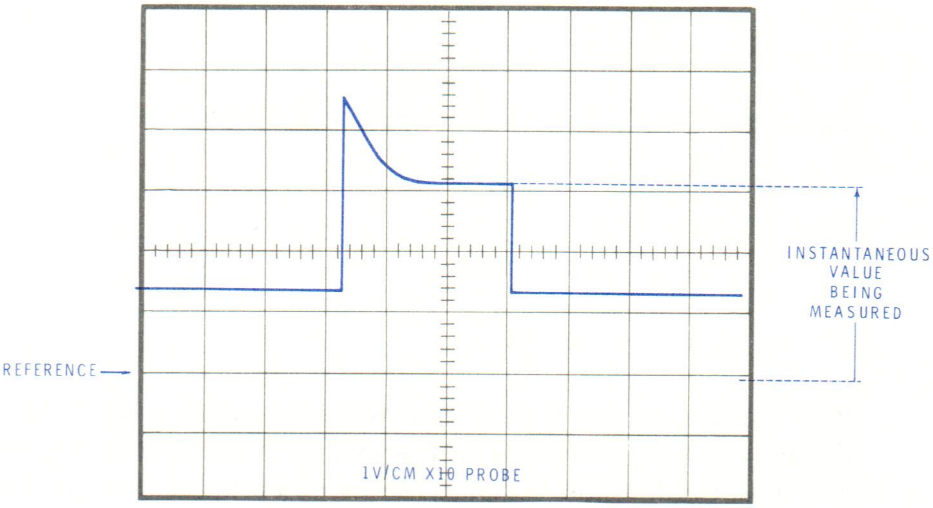


Figure 60

8. Count the number of divisions for the reference line to the instantaneous value being measured. In Figure 60, we are measuring to the plateau of the waveform. However, any other point on the waveform could be selected.

9. Multiply the number of divisions times the **VOLTS/CM** times the probe attenuation.

   For example, assume that the waveform in Figure 60 is being measured with **VOLTS/CM** setting of 1 V/cm and a ×10 probe is being used. To find the instantaneous value, use vertical deflection × V/cm × probe attenuation = instantaneous voltage. Substituting the proper values, we have $3.2 \times 1 \times 10 = 32$ V. Thus, the instantaneous value is 32 volts.

You now have the three basic voltage measurements that can be made with an oscilloscope. There are many applications of these measurements which you will use; however, they are all based on one or more of these techniques.

Time Duration

Before we measure time with the oscilloscope, we will review the time relationships of some waveforms. The first and perhaps the most common is the sine wave as shown in Figure 61. We see here that a cycle is complete when the voltage or current has gone from zero through a positive alternation and a negative alternation back to zero. The time it takes to complete one cycle is the period of the waveform. This period or time can be measured with the oscilloscope.

In your earlier lessons, you learned that frequency = $\frac{1}{\text{time}}$. Therefore, if you know the time, it is a simple mater to compute the frequency.

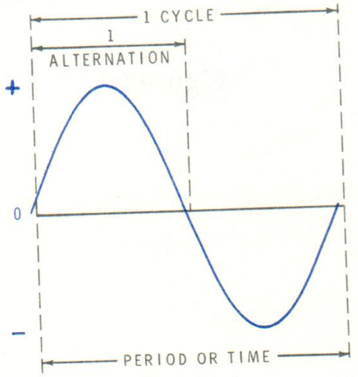


Figure 61

To measure the time or period of a sine wave, use the following procedure:

1. Set up the scope using the procedures mentioned earlier.
2. Connect the signal to the vertical input and adjust the controls for a stable display.
3. Be sure that the **SWEEP/VAR** control is in the **CAL** position.
4. Set the **TIME/CM** control for more than one but less than three – if possible – complete waveforms.
5. Using the vertical position control, position the waveform so it is approximately bisected by the horizontal centerline.
6. Using the horizontal position control, position the waveform so it crosses the horizontal centerline at one of the major vertical lines. The presentation should be similar to that shown in Figure 62.

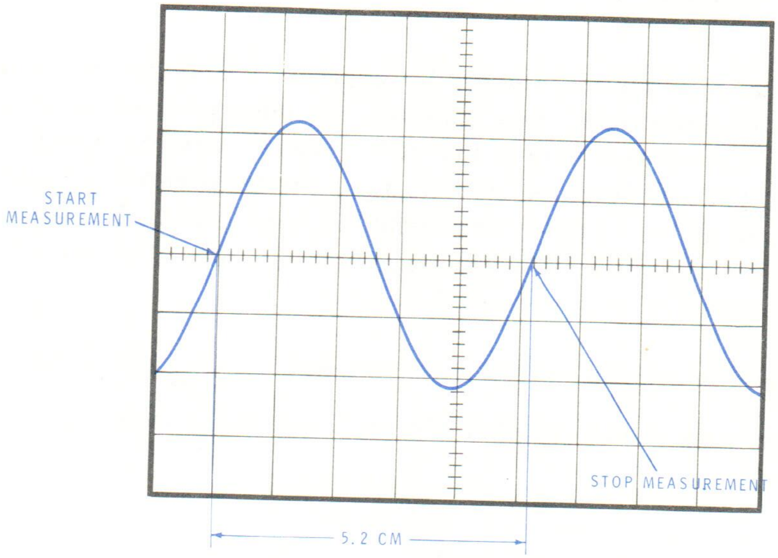


Figure 62

7. Count the number of divisions between the first crossing of the horizontal centerline and the second crossing in the same direction. In Figure 62 the distance is 5.2 cm.

8. Multiply the number of divisions times the setting of the **TIME/ CM** control.

   For example, assume that the TIME/CM control is set at 20 μS/Div and the number of divisions is 5.2 as indicated above. The time or period of one cycle will be:

   $$\text{time} = \text{number of divisions} \times \text{sweep setting}$$

   or

   $$t = 5.2 \times 20\ \mu\text{Sec.}$$

   $$t = 104\ \mu\text{Sec.}$$

   Frequency may be found by:

   $$\begin{aligned} f &= \frac{1}{t} \\ &= \frac{1}{104\ \mu\text{Sec.}} \\ &= 9.6\ \text{kHz} \end{aligned}$$

We have consistently used cm as a unit of distance when measuring both voltage and frequency because it is one of the most common units. You should remember, however, that any unit of measure can be used. The only thing that matters is the calibration in units/division.

Pulse Measurements

A pulse is a voltage that rises sharply from some value, usually zero, to another value, remains at that value for a period of time, then returns to the original value. If this excursion is repeated periodically, a pulse string exists. In today's world of computers and other digital electronics, the pulse is one of the most common waveforms requiring measurement. The oscilloscope is probably the best instrument for measuring pulse waveforms. However, before we discuss pulse measurement, we will briefly review the characteristics of the pulse waveform. Figure 63 shows the various times involved in a pulse waveform and should be referred to during this explanation.

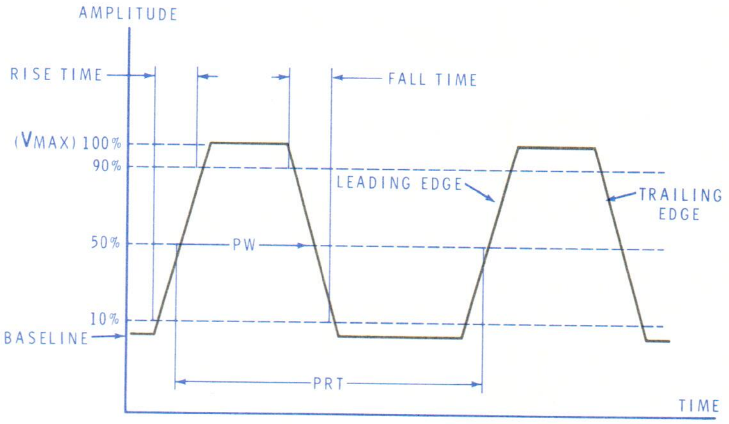


Figure 63

Each pulse will have a certain amplitude or voltage level (V_{max}). Since nothing can happen instantaneously, some time is required for the voltage to rise from the baseline voltage to V_{max}. This is known as rise time (Tr) and is defined as the time required for the voltage to change from 10% of V_{max} to 90% of V_{max}. The 10% and 90% figures have been selected because most pulses have a certain amount of distortion at the base line and the peak, which makes it difficult to obtain a precise measurement at those points. Figure 64 shows some of the more common types of distortion. This distortion must be compensated for when making pulse measurements.

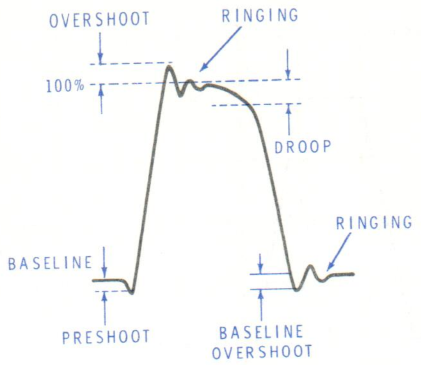


Figure 64

Once the pulse has risen to its maximum value, it will remain there for a period of time, then rapidly drop to the baseline voltage. The time required for a pulse to decrease from 90% of V_{max} to 10% of V_{max} is known as fall time (Tf) as shown in Figure 63.

The duration of the pulse, or how long it remains above the 50% point is known as the pulse width (PW). Thus, pulse width is measured at the 50% point on the waveform.

The time from the 50% point on the leading edge of one pulse to the 50% point on the leading edge of the next pulse is called the pulse recurrence time (PRT). The PRT of a pulse waveform is analogous to the period of a sine wave. Thus, the number of pulses-per-second, which is known as the pulse recurrence frequency (PRF), can be calculated by $PRF = \frac{1}{PRT}$.

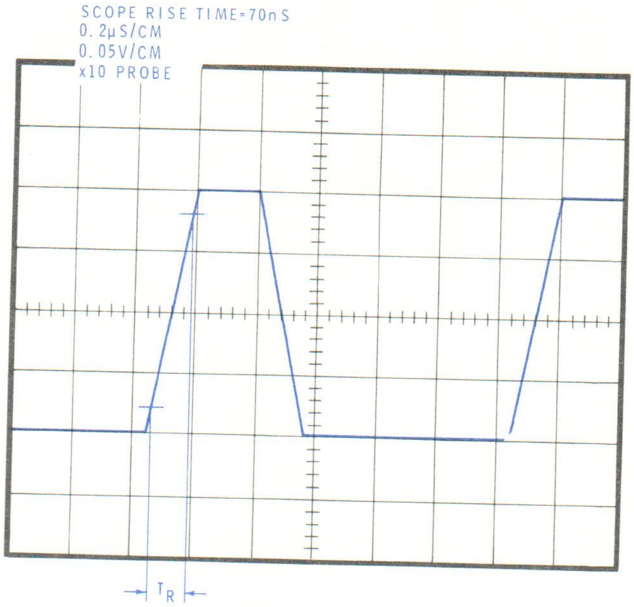


Figure 65

For example, assume that the CRT display and the control settings are as indicated in Figure 65. The waveform is positioned properly for measuring PW and PRT.

$$\mathrm{PW} = 1.4\ \mathrm{CM} \times 0.2\ \mu\mathrm{S/CM}$$

$$= 0.28\ \mu\mathrm{S}$$

$$\mathrm{PRT} = 6\ \mathrm{CM} \times 0.2\ \mu\mathrm{S/CM}$$

$$= 1.2\ \mu\mathrm{S}$$

$$\mathrm{PRF} = \frac{1}{1.2\ \mu\mathrm{S}}$$

$$= 833\ \mathrm{kHz}$$

The rise time displayed on the CRT (T_{rd}) is approximately 0.6 CM.

$$\begin{aligned} T_{rd} &= 0.6\ \text{CM} \times 0.2\ \mu\text{S/CM} \\ &= 0.12\ \mu\text{S} \\ &= 120\ \text{nS} \end{aligned}$$

This is the displayed rise time and does not accurately represent the rise time of the square wave being measured. The rise time of the scope is a determining factor in the accuracy of the measurement. The relationship may be shown by the following formula:

$$T_{rd} = \sqrt{T_{rd}{}^2 + T_{rw}{}^2}$$

Where T_{rd} equals the displayed rise time, T_{rs} equals the rise time of the scope and T_{rw} is the rise time of the waveform being measured. Thus, to find the rise time of the waveform being measured use:

$$T_{rw} = \sqrt{T_{rd}{}^2 - T_{rs}{}^2}$$

which in this case is:

$$\begin{aligned} T_{rw} &= \sqrt{120\ \text{ns}^2 - 70\ \text{ns}^2} \\ &= 97\ \ \text{nS} \end{aligned}$$

If the displayed rise time is at least three times the scope rise time, the rise time of the scope may be ignored and the accuracy of the measurement will be within 5%. If the displayed rise time is five times the scope rise time, the accuracy will be within 2%. Of course, the above inaccuracies are in addition to any inaccuracies in the sweep timing circuits.

When the displayed rise time approaches the rise time of the scope, it is impossible to obtain an accurate measurement. Therefore, to measure fast rise time, the scope must have a very fast rise time also. However, the very fast rise time may not be required to measure other waveform parameters such as PW and PRT.

X-Y Measurements

We mentioned earlier in our discussion of the basic oscilloscope block diagram (Figure 19, Page 3-30) that there were two possible inputs to the horizontal amplifier, one from the sweep generator and the other from an external source. At this time, we will study the action of the oscilloscope with other than a sweep voltage applied to the horizontal deflection plates.

Assume that the inputs to the vertical and horizontal amplifiers are two sine waves of the same frequency and amplitude. Also, assume that the two signals are in phase. Figure 66 shows how the presentation will appear on the CRT. AT T_0, both inputs are at zero volts. Therefore, no deflection occurs and the electron beam will be positioned at the center of the CRT. At T_1, both signals are positive and the beam is deflected upward and to the right, placing the spot in the upper right corner of the CRT. At T_2, the beam has returned to the center and at T_3, both signals are negative, deflecting the beam to the lower left corner of the CRT. At T_4, both signals have returned to zero and the beam is back in the center. Thus, we can see that the result of two sine waves in phase is a straight line. If the two signals are of equal amplitude, the line on the CRT will be at a 45° angle as shown. However, if the vertical signal is larger in amplitude, the angle will be greater than 45°. If the horizontal signal is larger, the angle will be less than 45°.

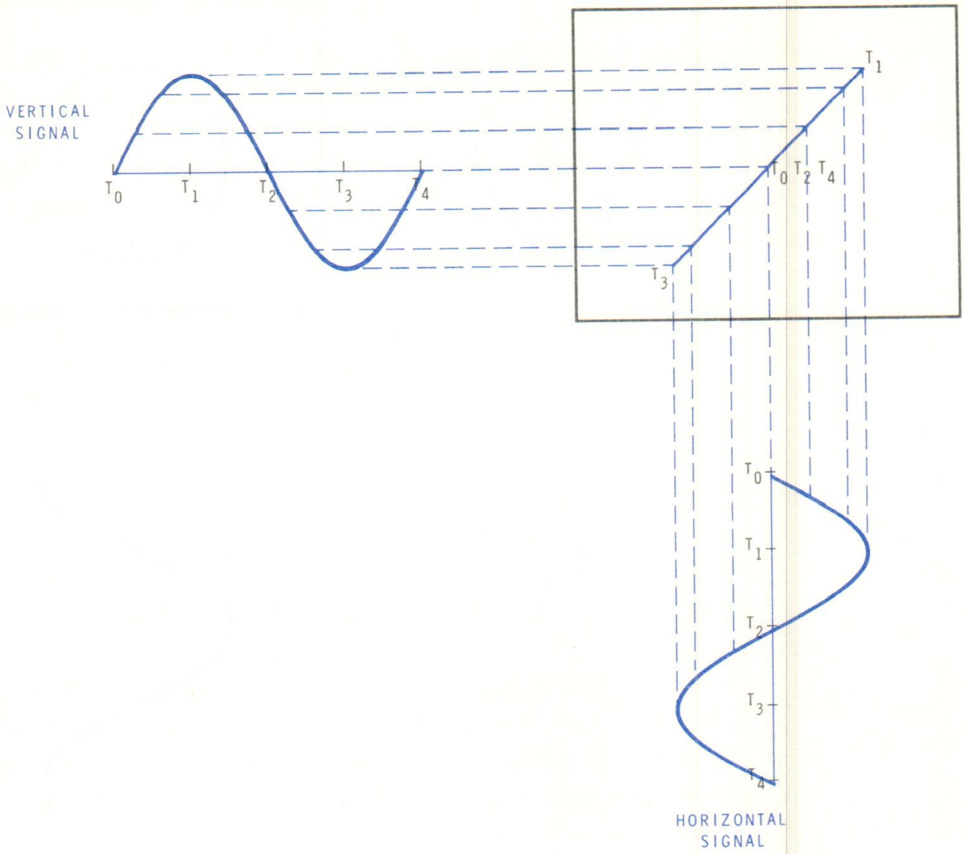

VERTICAL SIGNAL
T_0
T_1
T_2
T_3
T_4
T_1
T_0
T_2
T_4
T_3
T_0
T_1
T_2
T_3
T_4
HORIZONTAL SIGNAL

Figure 66

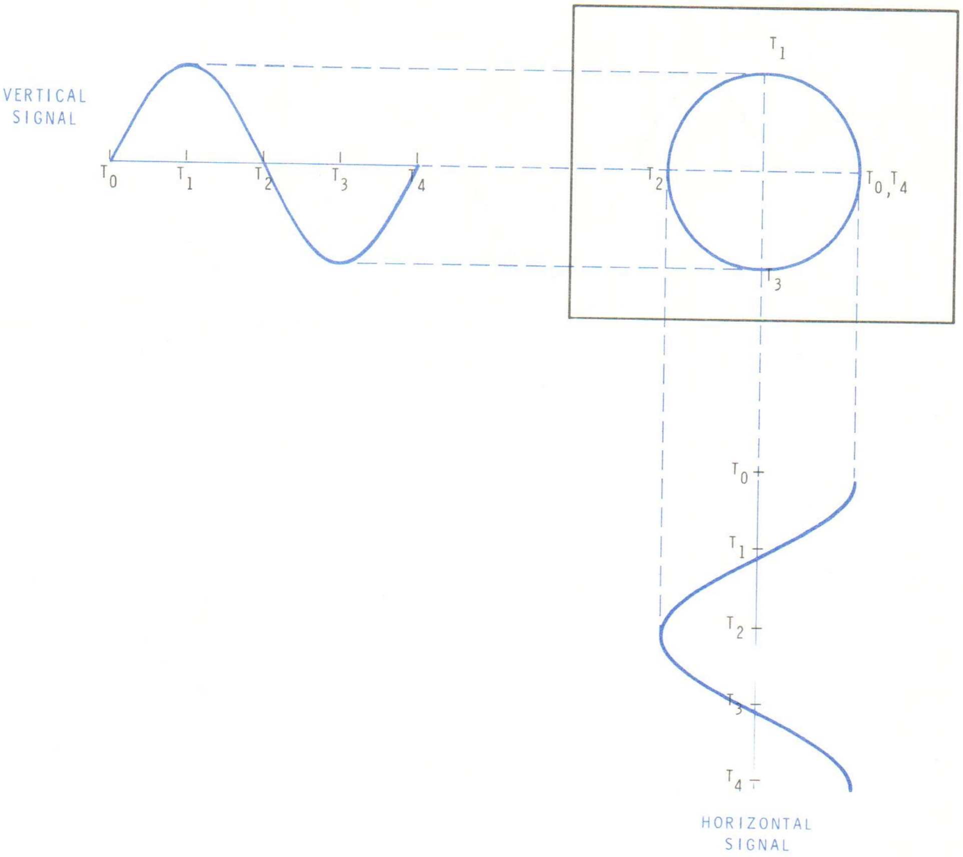


Figure 67

As long as the two inputs are in phase, the result will be a straight line. When the two signals are of the same frequency and amplitude but out of phase, the result will not be a straight line. Figure 67 shows the inputs 90° out of phase. The result, as you can see, is a circle on the CRT. If the phase difference is other than 90°, the result will be an elliptical presentation. An elliptical pattern will also be produced if the inputs are of unequal amplitude.

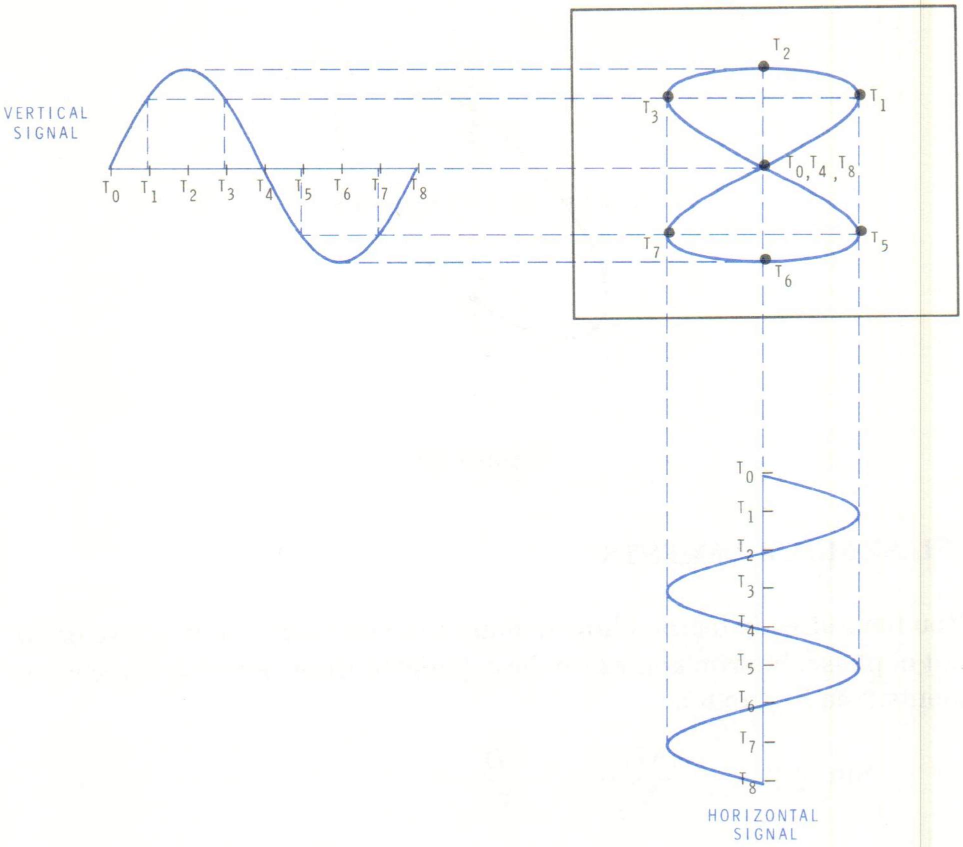


Figure 68

When the two inputs are of different frequencies, a more complicated presentation is produced. Figure 68 shows what happens when the horizontal is exactly twice the frequency of the vertical input. Notice that there is a direct relationship between the number of loops and the frequency difference. One frequency is twice the other and there are two loops. We will use this ratio later to determine an unknown frequency. The presentations just illustrated are called **Lissajous** figures. They can be used to compare the phase and frequency difference between two waveforms. The standard procedure is to apply the reference signal to the horizontal input and the unknown frequency or phase to the vertical input.

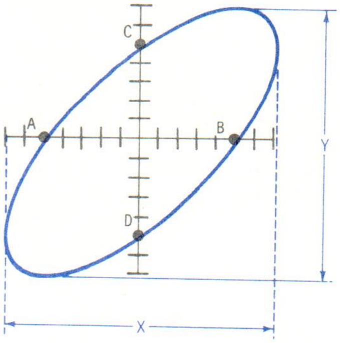


Figure 69

PHASE MEASUREMENTS

You have already learned how to determine if signals are in phase or 90° out of phase. Interim angles can be calculated from two simple measurements. See Figure 69.

$$\text{Sin } \angle \phi = \frac{AB}{X} = \frac{CD}{Y}$$

In Figure 69, AB equals about 10 divisions and X equals about 14 divisions. Therefore,

$$\text{Sin } \angle \phi = \frac{10}{14}$$

$$= 0.714$$

Looking at the table of trigonometric functions in Appendix A, we find that the angle corresponding to a sine of 0.714 is nearest to 46°. Thus, the phase difference between the vertical and horizontal inputs appears to be 46°. Actually, it may be 46°, 136°, 226°, or 316°, as this procedure does not tell us which quadrant the angle is in.

Part of the ambiguity is easily resolved. Figure 70 shows how this can be done. In this illustration, A is a 0° or 360° difference, B is 45° or 315°, C is 90° or 270°, D is 135° or 225° and E is 180°. The remaining 180° ambiguity cannot be resolved using this procedure without additional equipment.

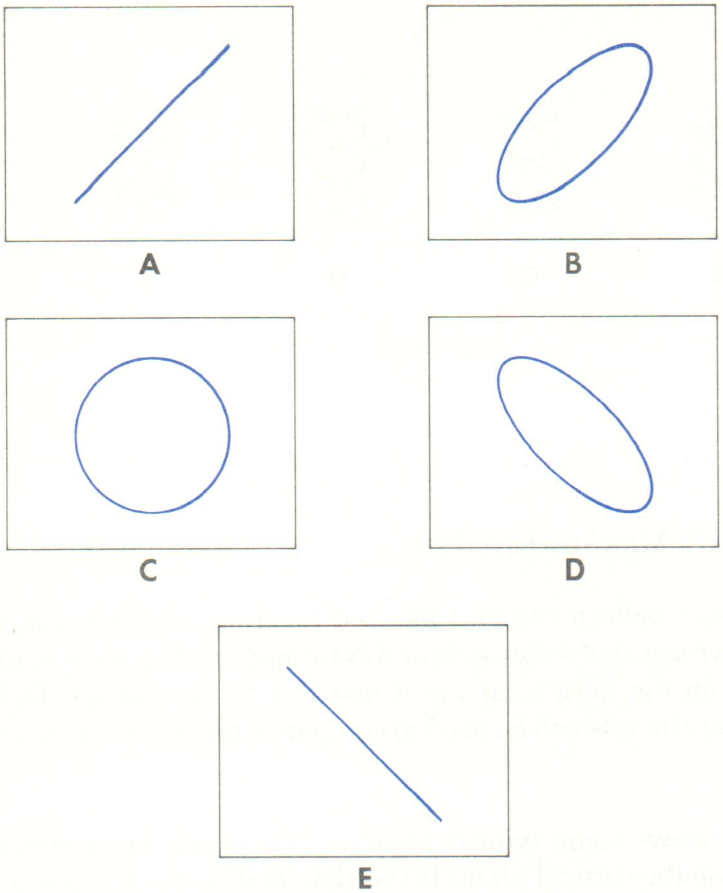


Figure 70

Phase differences as small as 1° can be detected using this procedure. However, as the difference approaches 90°, the measurement becomes more difficult. You should remember that the phase difference displayed on the CRT includes any phase shift induced by the oscilloscope amplifiers, leads, and probes. Therefore, a single signal should be fed to both inputs in parallel to detect any equipment induced difference. A good modern scope should induce no appreciable phase difference; however, if necessary, continuously variable delay lines can be connected in series with the leads to compensate for the shift.

Another potential source of error is the presence of harmonics on either of the inputs. Even a low level of harmonics can cause a significant error.

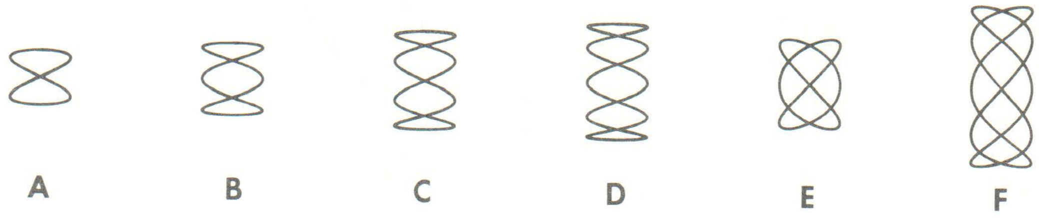


Figure 71

FREQUENCY MEASUREMENTS

The Lissajous pattern can also be used for frequency measurement. In Figure 68 we saw that a figure eight was formed on the screen by placing a frequency on the horizontal input that was twice that on the vertical input. This principle can be used to compare a known frequency with an unknown.

Figure 71 shows some typical patterns that would be obtained if the frequency on the vertical plates is less than that on the horizontal plates. If the reference frequency is applied to the horizontal plates, the unknown frequency can be found by dividing the reference frequency (f_r) by the number of horizontal loops (N_h) then multiplying by the number of vertical (N_v) loops. For instance, Figure 71C has four vertical loops and one horizontal loop. If the reference frequency is 1000 Hz, the unknown frequency will be

$$
\begin{aligned}
f_u &= \frac{f_r}{N_h} \times N_v \\
&= \frac{1000}{1} \times 4 \\
&= 4000 \text{ Hz}
\end{aligned}
$$

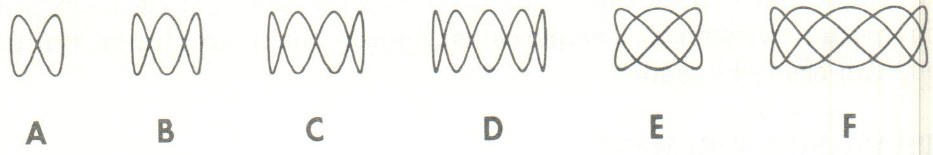


Figure 72

Figure 72 shows some patterns where the reference frequency is less than the unknown. The procedures for finding the unknown frequency is the same as before.

$$f_u = \frac{f_r}{N_h} \times N_v$$

Thus, if we assume the same 1000 Hz reference and calculate the unknown frequency for Figure 72E, we have:

$$f_u = \frac{1000}{2} \times 3$$

$$= 1500 \text{ Hz}$$

Thus, we can see that it is not necessary for the unknown frequency to be an exact multiple or sub-multiple of the reference. However, there is a practical limit to the number of loops that can be accurately counted.

It may appear that frequency measurement by means of a Lissajous pattern is easy. It is not. Accurate frequency measurement requires a considerable amount of skill. In most cases, it is difficult to obtain a stationary pattern which is required for accurate measurement. However, if an accurately calibrated reference source is used, very accurate measurements can be made.

Phase measurement is not as difficult, and the oscilloscope is one of the best phase detecting devices available.

Dual Trace Measurement

As you might expect, the major application of the dual trace scope is comparing two signals. Comparisons of phase, shape, amplitude, timing, etc. can easily be made.

PHASE MEASUREMENT

When measuring phase with the dual trace scope, start by setting the scope for dual trace operation using your handbook as a reference. Feed one of the signals to the A channel and the other to the B channel. It is not necessary that the two signals be of the same amplitude, frequency, or shape. Do not, however, overdrive the vertical amplifiers.

Adjust the TIME/DIV and HORIZONTAL GAIN CONTROLS so that either one alteration or one complete cycle of the reference waveform requires exactly nine major horizontal divisions. Either channel can be used for a reference, however, the scope should be triggered off the reference waveform. It is also normal practice to use the lower frequency signal for reference when the inputs are of a different frequency. The horizontal sweep does not need to be calibrated for this measurement so the horizontal gain control can be adjusted as needed for proper display.

Figure 73 shows a typical display with one alteration equal to nine divisions. Since one alteration is equal to 180 electrical degrees, each division will equal $\frac{180}{9}$ or 20 degrees. Thus, in the waveform shown, waveform A leads wave B by three divisions or 60 degrees. The dual trace method of phase measurement is very accurate. However, you must be sure that both waveform A and waveform B are vertically centered.

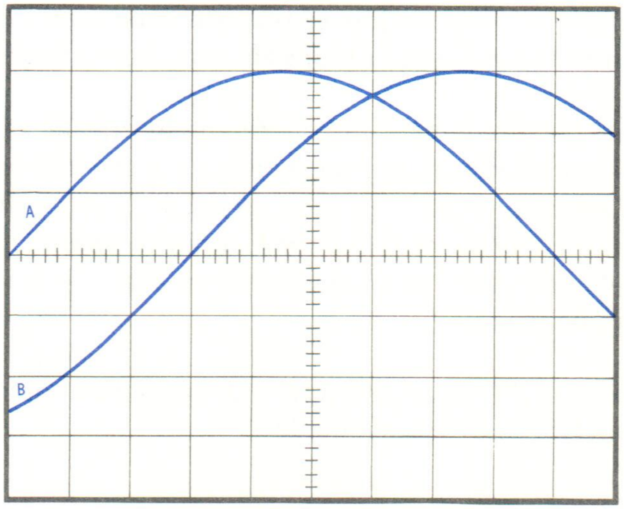


Figure 73

TIME DIFFERENCE

Time difference measurements are a snap with the dual trace scope. Set up is similar to that used for phase measurements. However, for time measurement, the horizontal time base control must be in the CALIBRATE position. Adjust the TIME/DIV until both pulses appear on the CRT as shown in Figure 74. The vertical control should be adjusted so the waveforms are bisected by the major horizontal line as shown. The time difference between the pulses can then be found by counting the number of divisions from the leading edge of the first pulse to the leading edge of the next pulse and multiplying that times the μS/DIV setting. For instance, in Figure 74, it is three divisions from the leading edge of A to the leading edge of B. Three divisions times 2 μS per division equals a delay of 6 μS.

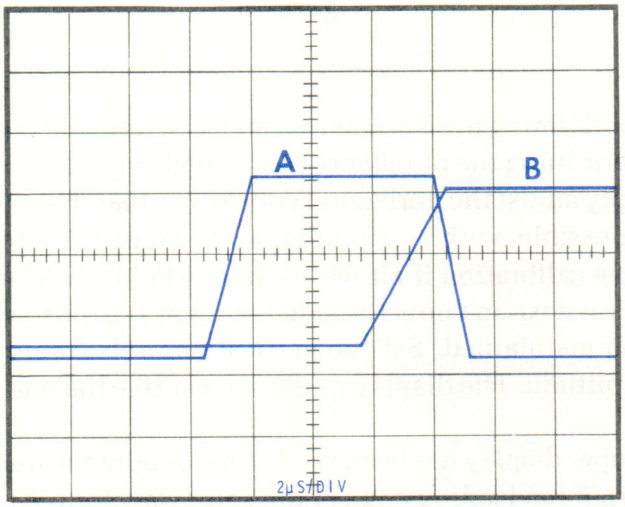


Figure 74

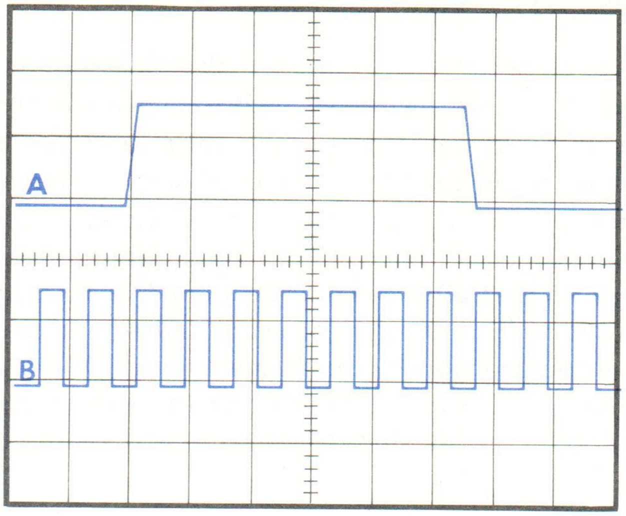


Figure 75

Another useful timing measurement which can be made with a dual trace scope is determining the number of pulses that occur during a given gate length. Simply adjust the horizontal controls so that the gate is expanded as much as possible, without running off the screen. There is no need to maintain time calibration if all we are interested in is relative numbers. However, if we wish to know the gate length or the pulse width, calibration must be maintained. Set the vertical controls for any comfortable viewing amplitude. The display might appear like the one in Figure 75.

Once the proper display has been established, count the number of pulses that occur from the leading edge of the gate (waveform A) to the trailing edge of the gate. In Figure 75, seven pulses occur during gate time.

OTHER USES

There are many more ways that the dual trace scope can make your troubleshooting easier. The output of an amplifier can be compared to the input. Channel A of a stereo amplifier can be compared with channel B. Simultaneous comparisons of amplitude, phase, frequency, time, distortion, and other factors can be made in this manner. Of course, many of these factors can be checked with a single trace scope, but the dual trace does a better job. In many digital applications, the dual trace scope becomes essential.

Programmed Review

78. Although the oscilloscope is one of the most versatile instruments, it is capable of measuring only ____________ and ________.

79. (voltage; time) The value of voltage that is measured with the oscilloscope is the ________________ value.

80. (peak-to-peak) Both AC and DC voltage $\underset{\text{may/may not}}{\_\_\_\_\_\_\_\_}$ be measured with an oscilloscope.

81. (may) When measuring voltages derived from a 60 Hz power source, ________ triggering would normally be used.

82. (line) For most other measurements, ____________ triggering would be used.

83. (internal) The amplitude of the signal being measured is equal to the ________ ____ ____________ times the ________ ________ ____________ times ________ ____________.

84. (number of divisions; volts per division; probe attenuation). To measure time, multiply the number of horizontal ____________ times the ________ ______ ________.

85. (divisions; time per division) Frequency can then be calculated by the formula ________.

86. ($f = \frac{1}{t}$) When measuring pulses of voltage, the period of time from the 50% point on the leading edge to the 50% point on the trailing edge is the ________ ________.

87. (pulse width) The time required for the voltage to change from 10% of V_{max} to 90% of V_{max} is known as ________ ________.

88. (rise time) Rise time ________ always be read directly from the scope.
may/may not

89. (may not) The formula for finding the rise time of a waveform (T_{rw}) using the rise time of the scope (T_{rs}) and the displayed waveform (T_{rd}) is ________.

90. ($T_{rw} = \sqrt{T_{rd}^2 - T_{rs}^2}$) When two waveforms are compared, one on the horizontal channel and the other on the vertical channel, the result is a ________ figure.

91. (Lissajous) Lissajous figures can be used for ________ and ________ comparisons.

92. (phase; frequency) Phase and time differences are more easily measured using a ________ ________ scope.

(dual trace)

Experiment 6

LISSAJOUS MEASUREMENTS

OBJECTIVE: To demonstrate how Lissajous Figures can be used for measuring phase and frequency.

Material Required

Oscilloscope, Heathkit Model IO-4541 or equivalent.

Probes or leads for connecting both vertical and horizontal inputs.

Heathkit Electronic Design Experimenter, Model ET-3100

One 1 k ohm, 5%, 1/4 watt resistor.

One .1 μF capacitor.

Introduction

In the first section of this experiment, you will construct a simple RC circuit and measure the phase shift across the capacitor compared to the input signal. This phase will be somewhere between 0° and 90°. The Heathkit Model IO-4541 Oscilloscope introduces only a small amount of phase shift into our measurement. This approximately 1° phase shift will be ignored for our purposes. If your oscilloscope introduces a significant shift, you will have to subtract it from the measured phase shift.

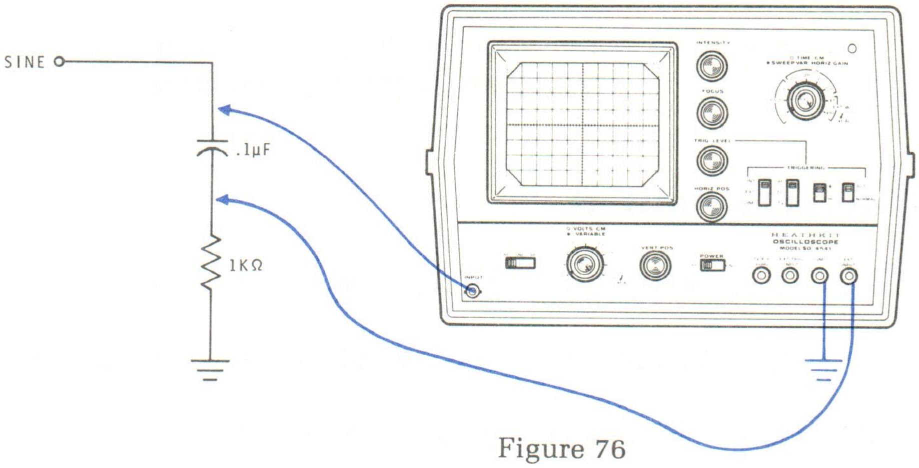


Figure 76

Procedure

1. Turn on the oscilloscope using the procedure in steps 1 through 12 of Experiment 5.
2. On the ET-3100 Trainer, connect the circuit shown in Figure 76.
3. Select the HIGH frequency range on the generator section of the Trainer.
4. Turn the FREQ control fully counterclockwise (CCW).
5. Connect the oscilloscope to the circuit as shown in Figure 76. Be sure that the scope ground is connected to the Trainer ground.
6. Set the **TIME/CM** control to the ×1 position.
7. Adjust the **HORIZ GAIN** and **HORIZ POS** controls until the presentation is 6 cm long and horizontally centered on the CRT.
8. Turn the **VOLTS/CM** control to 0.1. If necessary, adjust the **VARIABLE** control to prevent overdriving the scope.
9. Vertically center the presentation.

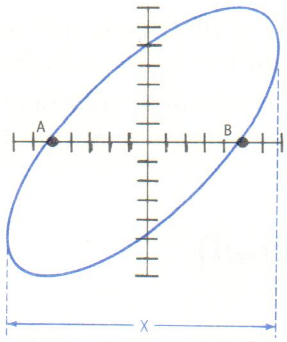


Figure 77

10. On your oscilloscope, count the number of minor divisions between points A and B as shown in Figure 77.

    AB = ______________ divisions.

11. Count the number of divisions for measurement X as shown in Figure 77.

    X = ____________ divisions

12. Calculate the sine of the phase angle (ϕ)

    $$\text{Sin } \phi = \frac{AB}{X}$$

    Sin ϕ = __________

13. Find the angle in the table of natural functions in Appendix A.

    $\angle \phi$ = __________°

Discussion

You have seen how the Lissajous figure can be used to determine the phase difference between two signals. Using the value in this experiment, the angle should have been about 30° to 35°. Changing either frequency, capacitance, or resistance will cause the phase angle to change. Therefore, your measurement may be different.

In the next section of this experiment, you will use the Lissajous figures to compare an unknown frequency with a known frequency. For a known frequency use the 60 Hz line signal available on the Trainer, and for the unknown frequency, use the sine wave output from the signal generator on the Trainer.

Procedure (continued)

14. Using the same procedure you used earlier in this experiment, turn on the oscilloscope and obtain a display.

15. Place the **VOLTS/CM** control in the 1 position.

16. Using a ×10 probe, connect the vertical input of the scope to terminal 1 of the LINE FREQ on the Trainer. Connect the ground clip to the ground position on the Trainer.

17. Connect the EXT INPUT of the scope to the SINE terminal of the GENERATOR section of the Trainer.

18. Select the LOW range position of the GENERATOR.

19. Turn the FREQ control fully CCW.

20. Place the **TIME/CM** control on the oscilloscope to the ×10 position.

21. Very slowly increase the frequency of the generator until a stationary Lissajous figure is obtained on the CRT.

    NOTE: This adjustment is very sensitive and difficult. In addition, due to the oscillator instability, the display will not remain stationary for long.

22. Count and record the number of horizontal loops ________.

23. Count and record the number of vertical loops ______.

24. Divide the reference or line frequency of 60 Hz by the number of horizontal loops.

25. Multiply the result of step numbers 24 times the number of vertical loops. Record the result which is the generator frequency.

    F = __________ Hz.

26. Repeat steps 21 through 25 for as many points as you can get a stable display.

Discussion

You will notice that due to the flattening of the peaks on the line frequency, the observed waveform is not exactly like the ideal waveform you studied in the text. There is some flattening at the top and bottom of the display. However, even with a "perfect" sine wave of line frequency, the tops and bottoms of the display are flattened somewhat. This has no effect on the accuracy of the frequency measurement.

You will probably also notice that the lower frequencies – smaller number of loops – are easier to stabilize and measure. The maximum number of vertical loops that can be effectively counted is about six. However, with care, you may be able to go higher.

Experiment 7

DIGITAL MEASUREMENT

OBJECTIVE: To demonstrate how various pulse measurements can be made on an oscilloscope.

Material Required

Oscilloscope, Heathkit Model IO-4541 or equivalent.

Heath PKW-101 ×10 Probe or equivalent.

Heathkit Electronic Design Experimenter, Model ET-3100

One 7490 Integrated Circuit.

12-inch hookup wire.

Introduction

In this experiment, you will see how you can determine various pulse measurements such as pulse width (PW), pulse recurrence time (PRT), pulse recurrence frequency (PRF), duty cycle (DC), rise time, fall time, amplitude, and the average value by using an oscilloscope.

Procedure:

1. Turn on the oscilloscope using the procedure in steps 1 through 12 of Experiment 5.

2. Set the **TIME/CM** control to the 20 μS position and the **SWEEP VAR/HORIZ GAIN** to CAL.

3. Place the **VOLTS/CM** control to 0.2 and the **VARIABLE** to CAL.

4. Connect the square wave output from the signal generator to the vertical input of the oscilloscope. Use a ×10 probe it it is available.

5. Adjust the frequency of the generator section of the ET-3100 Trainer to approximately 12.5 kHz. The waveform should look something like the one in Figure **78**. Once a frequency setting has been established, it should remain undisturbed.

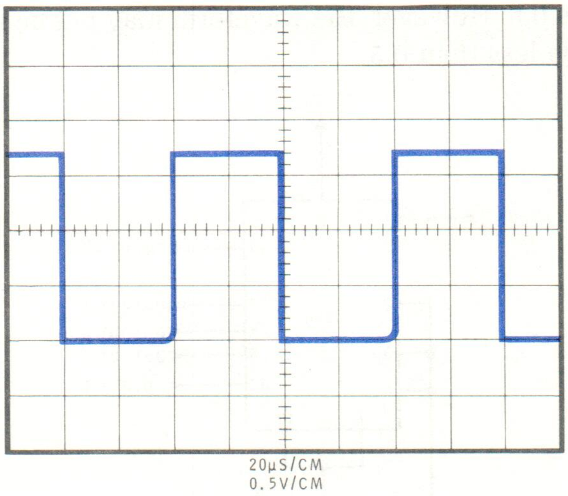


Figure 78

6. Measure and record the pulse width (PW).

PW = ____________.

7. Measure and record the pulse recurrence time (PRT).

PRT = ____________.

Procedure (continued)

8. Calculate the duty cycle (DC) by using the formula $DC = \frac{PW}{PRT}$

DC = ____________.

9. Calculate the pulse recurrence frequency (PRF) using the formula

$PRF = \frac{1}{PRT}$.

PRF = ____________

Discussion

You should have obtained a PW of about 40 μS or a little less. The PRT for 12.5 kHz is 80 μS. Yours should be close. If the waveform is symmetrical, the DC will be 0.5. However, the waveform may not be symmetrical, so, the DC may be less than 0.5.

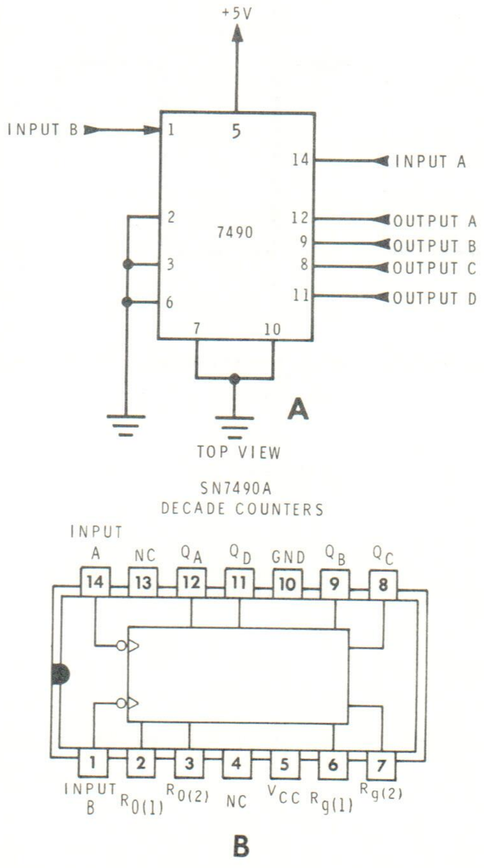


Figure 79

Procedure (continued)

10. Connect the circuit shown in Figure 79. Connect the output from the signal generator to input A, pin 14 of the IC. Connect pin 12, output A, to the vertical input of the scope. The waveform should look something like the one in Figure 80.

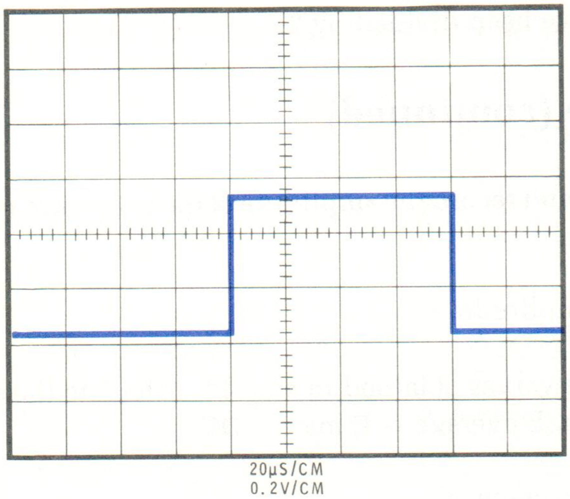


Figure 80

11. Repeat steps 6 through 9.

PW = ________

PRT = ________

DC = ________

PRF = ________

12. What has happened to the PW and the PRT? ________
________.

13. What effect has this had on the duty cycle? ________
________.

14. How has the PRF been affected? ________.

Discussion

In this portion of the experiment, you first measured a pulse train as it came from the square wave generator, then you fed these pulses to a divide-by-two circuit and measured the output. This particular circuit would have caused the PRT to double. The PW will also have increased. If the waveform was symmetrical before, the DC will not have changed. However, if it was not symmetrical, the DC will have increased to 0.5 because the waveform at pin 12 should be symmetrical. In any case, the PRF would have been divided by 2.

Procedure (continued)

15. Measure and record the amplitude of the waveform you obtained in step 10.

    Amplitude = __________V.

16. Using the values obtained in step 11, calculate the average of the waveform. E average = E max × DC

    E average = ____________

17. Connect a jumper wire from pin 12 of the divider to pin 1.

18. Move the oscilloscope probe from output A (pin 12) to output D, (pin 11). The waveform should look like the one in Figure 81.

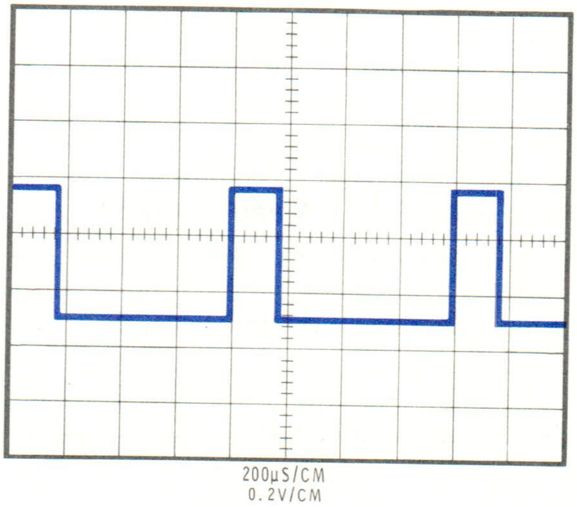


Figure 81

19. Measure and record PW, PRT, and amplitude. Change the **TIME/CM** control as necessary.

PW = ____________

PRT = ______________

Amplitude = ____________

20. Calculate DC, PRF, and E average.

DC = ____________

PRF = ____________

E average = ____________

21. What effect did this change have on PW? ____________________

22. What effect did this change have on PRT? ____________________

23. How did this affect duty cycle? ____________________

24. How did it affect PRF? ____________________

25. How did it affect average voltage? ____________________

Discussion

The waveform obtained from step 10 was applied to a divide-by-five circuit. The result of this division is a non-symmetrical waveform with a pulse width that is only one-fifth of the pulse recurrent time. This, of course, changed the ratio between PW and PRT, thus changing the duty cycle. A reduction in the average value of the waveform is the result. Obviously, the frequency has also decreased.

In the next section of this experiment, you will use the external trigger capability of the oscilloscope to allow you to view a selected portion of the input waveform.

Procedure (continued)

26. With the vertical input of the oscilloscope connected to pin 11 of the divider, select negative trigger polarity and a sweep speed of 20 μs/CM.

27. Connect the **EXT TRIG INPUT** to pin 11 of the divider and select **EXT** triggering.

28. Adjust the TRIG LEVEL control so that the negative portion of the waveform is displayed.

29. Adjust the SWEEP VAR control until the positive-going edge of the next pulse appears on the right edge of the CRT. Only the very edge of this pulse should be visible, as shown in Figure 82.

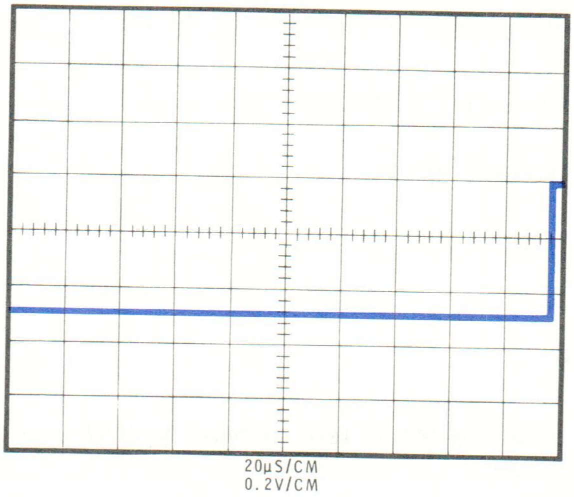


Figure 82

30. Connect the vertical input of the oscilloscope to the output of the square wave generator.

31. Count the number of pulses that appear on the scope.

No. pulses ____________

32. How does this number of pulses relate to the waveform measured at pin 11? ____________________

Discussion

The scope was triggered on the negative-going portion of the waveform at pin 11, and the length of the sweep adjusted to be equal to the negative portion of the waveform. Thus, the number of pulses equals the number that occurs during the negative portion of that waveform. Of course, since the **SWEEP VAR** control was moved from the **CAL** position, no time or frequency measurements can be made.

In the next portion of the Experiment, you will see how the oscilloscope can be used to measure the rise and fall time of a waveform.

Procedure (continued)

33. Turn the frequency control of generator section of the ET-3100 Experimenter fully clockwise and set the RANGE switch to HIGH.

34. Connect the circuit shown in Figure 83.

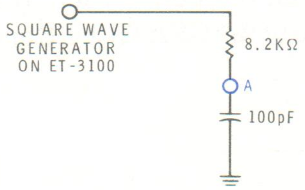


Figure 83

35. On the oscillosope, set the **TIME/CM** control to the 2 μS position and the **SWEEP VAR/HORIZ GAIN** to CAL.

36. Set the **VOLTS/CM** control to 0.5 and the **VARIABLE** to CAL.

37. Set the **TRIGGERING** controls to INT, A, "–", and AUTO.

38. Adjust the **TRIG LEVEL** control for a stable display.

39. Using a ×10 probe, observe the waveform at point A in Figure 83.

40. Measure the amplitude of the waveform in divisions. The actual voltage is unimportant for rise time measurement.

Number of Divisions = __________

41. Calculate ten percent and ninety percent of the previous measurement.

10% = __________

90% = __________

42. Adjust the **HORIZ POS** control until the base of the waveform crosses the center vertical line of the GRATICULE.

43. Adjust the **VERT POS** control until the base of the waveform is 10% below the center horizontal line of the GRATICULE.

44. Adjust the **HORIZ POS** control until the 90% point of the waveform intersects the center vertical line of the GRATICULE.

45. Measure the time between the point where the waveform crosses the center horizontal line of the GRATICULE and the center vertical line of the GRATICULE.

Rise Time = __________

Discussion

Your presentation should look something like the one in Figure 84. The waveform shown here is three major divisions plus two minor divisions in amplitude. Or, the amplitude is 17 minor divisions. The 10% point on this waveform is, therefore, 1.7 minor divisions from the base, and the 90% point is 15.3 minor divisions from the base or 1.7 minor divisions from the top. Since rise time is the time required for the waveform to rise from 10% to 90%, it can be measured between the point where the waveform crosses the horizontal reference line and the vertical reference line. In this case, rise time is equal to 1.8 major divisions with a **TIME/CM** of 2 μs, rise time is equal to 1.8 times 2 μs or 3.6 μs.

Don't be concerned if your values are quite different from these. Because of component and equipment tolerance, variations of up to 30% can be expected.

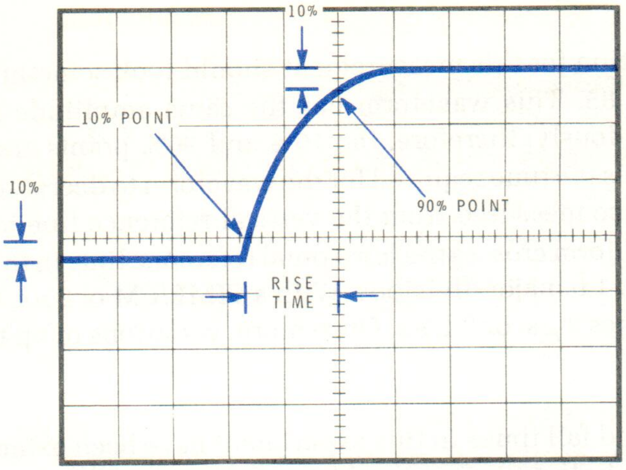


Figure 84

Procedure (continued)

46. Without disturbing any other controls, change the TRIGGERING from "−" to "+".

47. If necessary, readjust the **TRIG LEVEL** for a stable display.

48. Adjust the **HORIZ POS** control until the base of the waveform crosses the center vertical line of GRATICULE.

49. Adjust the **VERT POS** control until the base of the waveform is 10% below the center horizontal line of the GRATICULE.

50. Adjust the **HORIZ POS** control until the 90% point of the waveform intersects the center vertical line of the GRATICULE.

51. Measure the time between the center vertical line and the point where the waveform crosses the center horizontal line.

Fall Time = ____________

Discussion

Your presentation for this measurement should look something like the one in Fiugre 85. This waveform has the same amplitude as the one discussed previously; therefore, the 10% and 90% points are the same. Since fall time is the time required for the waveform to decrease from 90% to 10%, it can be measured from the vertical reference line to the point where the waveform crosses the horizontal reference line. In this case, fall time is equal to 1.6 major divisions. With a **TIME/CM** of 2 μs, fall time is equal to 1.6 times 2 μs, or 3.2 μs. Once more, variations of up to 30% can be expected.

Both the rise and fall times in this experiment have been extended by an RC circuit to make them long enough to measure with this scope. Because of the slow rise and fall times thus generated, no ringing or base line overshoot will be evident. In a practical digital waveform, with rise and fall times of a few nanoseconds, ring and overshoot will be present. However, the basic measurement procedure remains the same even though a much faster scope is required.

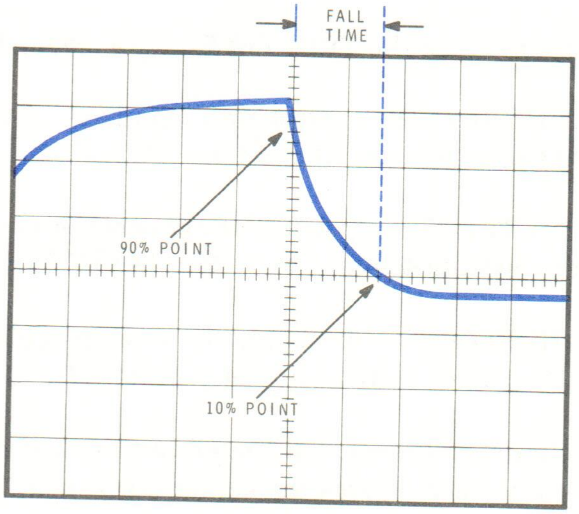


Figure 85

UNIT EXAMINATION

The following multiple choice examination is designed to test your understanding of the material presented in this unit. Place a check beside the multiple choice answer (A, B, C, or D) that you feel is most correct. When you have completed the examination, compare your answers with the correct ones that appear after the examination.

1. Part number 3 in Figure 86 is:

   A. The phosphor coated screen.
   B. The electron gun.
   C. The vertical deflection plates.
   D. The horizontal deflection plates.

2. What is the purpose of the phosphor coating on the screen of the CRT.

   A. To provide post deflection acceleration.
   B. To give off light when struck by electrons, thus providing a visual display.
   C. To prevent burning of the aquadag coating.
   D. To focus the electrons into a very thin beam, thus improving the readability of the display.

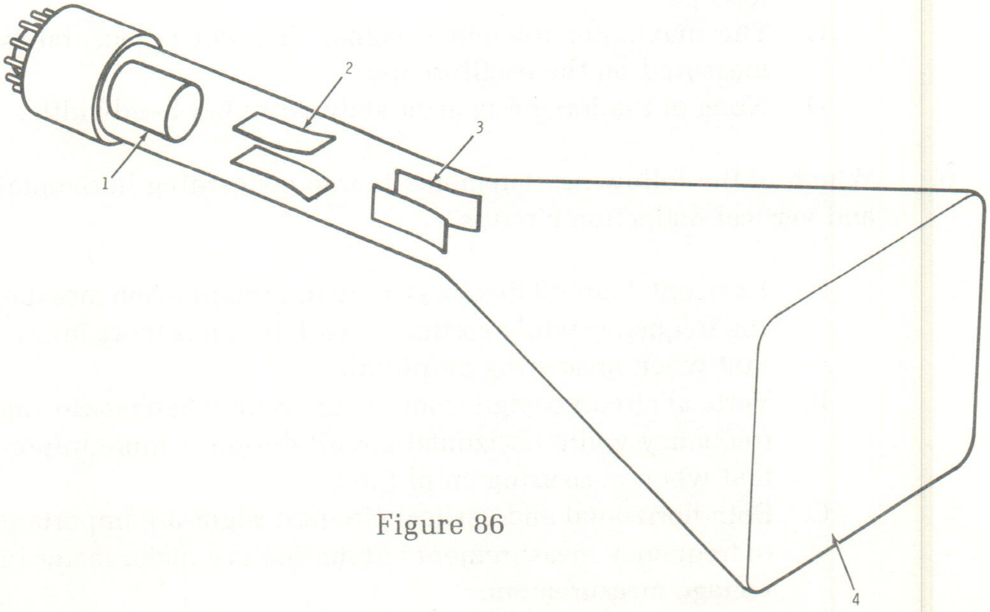


Figure 86

3. Select the statement that best describes how the electron beam is deflected within the CRT.

   A. Both plates of a pair go positive or negative at the same time by the same amount.
   B. One plate goes positive while the other goes negative.
   C. One plate is held at a constant potential while the other goes positive and negative.
   D. A deceleration potential is applied to the positive-going plate and an acceleration potential is applied to the negative-going plate.

4. The amount of voltage required to move the electron spot 1 cm on the face of the CRT is known as:

   A. Deflection sensitivity.
   B. Deflection potential.
   C. Oscilloscope sensitivity.
   D. Amplification factor.

5. The bandwidth of an oscilloscope is determined by:

   A. The maximum frequency signal that can be displayed on an oscilloscope.
   B. The range of frequencies between the minimum usable frequency and the maximum usable frequency of the oscilloscope.
   C. The maximum frequency signal that can be accurately measured on the oscilloscope.
   D. None of the foregoing accurately describes bandwidth.

6. Which of the following statements is true concerning horizontal and vertical deflection circuits?

   A. Horizontal circuit design is more important when measuring frequency while vertical circuit design is more important when measuring amplitude.
   B. Vertical circuit design is more important when measuring frequency while horizontal circuit design is more important when measuring amplitude.
   C. Both horizontal and vertical circuit designs are important to frequency measurement but neither is a major factor in voltage measurement.
   D. Both horizontal and vertical circuit design are of equal importance for both frequency and amplitude measurements.

7. The purpose of unblanking the scope is to:

   A. Turn off the electron beam during retrace time.
   B. Turn on the electron beam during retrace time.
   C. Turn off the electron beam during sweep time.
   D. Turn on the electron beam during sweep time.

8. A sweep that starts each time the input signal reaches a specified level is a:

   A. Triggered sweep.
   B. Free-running sweep.
   C. Recurrent sweep.
   D. Calibrated Sweep.

9. The main advantage of a triggered sweep is:

   A. Wider frequency range.
   B. More accurate calibration is possible.
   C. A more stable presentation can be obtained.
   D. It "free runs" at a predetermined frequency.

10. Which of the following is the correct definition of rise time?

   A. The time required for a waveform to change from minimum to maximum.
   B. The time required for a waveform to change from 10% of maximum to 90% of maximum.
   C. The time required for one pulse to be displayed on the scope.
   D. The time required for the vertical amplifier to reach maximum.

11. Which of the following statements is correct concerning bandwidth and rise time?

   A. A fast rise time requires a narrow bandwidth.
   B. A fast rise time requires a wide bandwidth.
   C. Rise time and bandwidth are unrelated.
   D. Rise time and bandwidth are related by the formula $T_r = 0.35BW$.

12. An oscilloscope power supply must:

    A. Be well regulated.
    B. Provide a variety of voltages.
    C. Be capable of producing very high voltages.
    D. All the above are correct.

13. A sweep magnifier is used to:

    A. Increase sweep speed.
    B. Decrease sweep speed.
    C. Enlarge a portion of the sweep in a vertical direction.
    D. Enlarge the sweep in a horizontal direction.

14. A delayed sweep:

    A. Uses a separate time base.
    B. Effectively enlarges a portion of the normal sweep.
    C. Is used in place of a magnifier.
    D. All the above.

15. Which of the following is the preferred method of dual trace generation at high sweep frequencies?

    A. Chop.
    B. Alternate.
    C. Use of two guns.
    D. It makes no difference.

16. At slower sweep speeds, the ________ method of dual trace generation is preferred while the ______________ method is preferred at higher sweep speeds.

    A. Alternate; alternate
    B. Chop; chop
    C. Alternate; chop
    D. Chop; alternate

17. In a storage CRT, storage is accomplished by:

   A. Flood gun electrons causing the surface of the storage mesh to become positive at the proper location.
   B. Write gun electrons causing the surface of the storage mesh to become positive at the proper location.
   C. Flood gun electrons causing the surface of the storage mesh to become negative at the proper location.
   D. Write gun electrons causing the surface of the storage mesh to become negative at the proper location.

18. Sampling oscilloscopes will NOT work on which of these types of information?

   A. Repetitive.
   B. Non-recurring.
   C. High frequency.
   D. Irregular shaped waveforms.

19. Oscilloscope voltage measurements are:

   A. Peak-to-peak.
   B. RMS
   C. Average.
   D. AC only.

20. Precise control of the sweep time is required when:

   A. Measuring voltage.
   B. Using Lissajous figures.
   C. Measuring frequency.
   D. All the above are correct.

21. Pulse width measurements are made:

   A. At the peak of the pulse.
   B. At the base of the pulse.
   C. Half way up the pulse.
   D. At the half power point.

22. Timing measurements:

    A. Require an XY presentation.
    B. Are made by adjusting the **SWEEP/VAR** control for a proper trace, then reading the time from the sweep dial.
    C. Must be made using Lissajous figures.
    D. Must be made with a calibrated sweep.

23. If two signals both having the same frequency and phase are applied to the inputs of an oscilloscope, one to the vertical input and the other to the horizontal input, the resulting display will be:

    A. A straight horizontal line.
    B. A straight diagonal line.
    C. A straight vertical line.
    D. A circle.

24. What is the bandwidth required for a rise time of less than 4 nanoseconds?

    A. 100 MHz.
    B. 35 MHz.
    C. 15 MHz.
    D. 5 MHz.

25. The rise time displayed on the CRT is 50 ns. If the rise time of the scope is 30 ns, what is the rise time of the waveform?

    A. 20 ns.
    B. 50 ns.
    C. 80 ns.
    D. 40 ns.

APPENDIX A
Table of Trigonometric Functions

Degrees	Sine	Cosine	Tangent	Degrees	Sine	Cosine	Tangent
0	0.000	1.000	0.000				
1	0.017	1.000	0.017	46	0.719	0.695	1.036
2	0.035	0.999	0.035	47	0.731	0.682	1.072
3	0.052	0.999	0.052	48	0.743	0.669	1.111
4	0.070	0.998	0.070	49	0.755	0.656	1.150
5	0.087	0.996	0.087	50	0.766	0.643	1.192
6	0.105	0.995	0.105	51	0.777	0.629	1.235
7	0.122	0.993	0.123	52	0.788	0.616	1.280
8	0.139	0.990	0.141	53	0.799	0.602	1.327
9	0.156	0.988	0.158	54	0.809	0.588	1.376
10	0.174	0.985	0.176	55	0.819	0.574	1.428
11	0.191	0.982	0.194	56	0.829	0.559	1.483
12	0.208	0.978	0.213	57	0.839	0.545	1.540
13	0.225	0.974	0.231	58	0.848	0.530	1.600
14	0.242	0.970	0.249	59	0.857	0.515	1.664
15	0.259	0.966	0.268	60	0.866	0.500	1.732
16	0.276	0.961	0.287	61	0.875	0.485	1.804
17	0.292	0.956	0.306	62	0.883	0.469	1.881
18	0.309	0.951	0.325	63	0.891	0.454	1.963
19	0.326	0.946	0.344	64	0.899	0.438	2.050
20	0.342	0.940	0.364	65	0.906	0.423	2.145
21	0.358	0.934	0.384	66	0.914	0.407	2.246
22	0.375	0.927	0.404	67	0.921	0.391	2.356
23	0.391	0.921	0.424	68	0.927	0.375	2.475
24	0.407	0.914	0.445	69	0.934	0.358	2.605
25	0.423	0.906	0.466	70	0.940	0.342	2.748
26	0.438	0.899	0.488	71	0.946	0.326	2.904
27	0.454	0.891	0.510	72	0.951	0.309	3.078
28	0.469	0.883	0.532	73	0.956	0.292	3.271
29	0.485	0.875	0.554	74	0.961	0.276	3.487
30	0.500	0.866	0.577	75	0.966	0.259	3.732
31	0.515	0.857	0.601	76	0.970	0.242	4.011
32	0.530	0.848	0.625	77	0.974	0.225	4.332
33	0.545	0.839	0.649	78	0.978	0.208	4.705
34	0.559	0.829	0.675	79	0.982	0.191	5.145
35	0.574	0.819	0.700	80	0.985	0.174	5.671
36	0.588	0.809	0.727	81	0.988	0.156	6.314
37	0.602	0.799	0.754	82	0.990	0.139	7.115
38	0.616	0.788	0.781	83	0.993	0.122	8.144
39	0.629	0.777	0.810	84	0.995	0.105	9.514
40	0.643	0.766	0.839	85	0.996	0.087	11.43
41	0.656	0.755	0.869	86	0.998	0.070	14.30
42	0.669	0.743	0.900	87	0.999	0.052	19.08
43	0.682	0.731	0.933	88	0.999	0.035	28.61
44	0.695	0.719	0.966	89	1.000	0.017	57.29
45	0.707	0.707	1.000	90	1.000	0.000	